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Economic Geology

and the

Bulletin of the Society of Economic Geologists

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ECONOMIC GEOLOGY

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ORE DEPOSITS AT CAMP ALBION, BOULDER COUNTY, COLORADO.

ERNEST E. WAHLSTROM.

ABSTRACT.

At Camp Albion, Boulder County, Colorado, an unusual assemblage of ore and gangue minerals is found in a sheared and brecciated zone cutting the contact between pre-Cambrian gneiss and a composite Tertiary monzonite stock.

Petrographic and chemical-mineralogic studies suggest that the ore was deposited from alkaline residual solutions resulting from prolonged and complex processes of differentiation and injection in a monzonitic magma.

A genetic classification of the deposit is difficult because the ore and gangue minerals do not appear to be consistent with the structural setting. However, it is concluded that the deposit may be classified as shallow mesothermal or, possibly, as deep "xenothermal" as Buddington has defined the word.

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INTRODUCTION.

THE ore deposits at Camp Albion constitute a rare lead-silver type, and, although the deposits have not as yet proved to be economically important, an unusual association of gangue and ore minerals in a seemingly anomalous structural setting is of sufficient interest to merit description. The deposits were discovered before 1900, and since then several attempts to work them have failed because of inaccessible location, rigorous climate, and the spotty distribution of the ore.

The deposits represent one phase of the extensive ore deposition that accompanied the Tertiary monzonite stock of the Audubon-Albion region and the nearby and genetically related stocks of the Caribou, Jamestown, Eldora, and Ward mining districts. All of these districts, except Camp Albion, have been noteworthy producers of gold, silver, and base metals.

Location.—Camp Albion lies just east of Lake Albion in the west central part of Boulder County, Colorado (Fig. 1). It is practically inaccessible in winter but in summer months may be reached by trails from University Camp or Silver Lake, which places are connected by roads from the towns of Ward and Nederland.

Field Work and Acknowledgments.—The writer spent three weeks at Camp Albion during the summer of 1932 and, with the assistance of Mr. Frank Bateman, made a plane table map of the region about Lake Albion. In subsequent field seasons up to and including that of 1937 the work was extended north to Mount Audubon and east to Ward so as to place the Camp Albion ore deposits in their proper regional setting.[1]

The writer wishes to express his gratitude to Professor L. C. Graton of Harvard University for his advice and aid in the laboratory studies and for his criticism of this paper. Professors R. D. Crawford and R. D. George of the University of Colorado contributed many valuable suggestions. The chemical and petrographic analyses and photomicrographs were made with the aid

[1] This work is described in a thesis submitted in 1939 to Harvard University for the degree Doctor of Philosophy.

of equipment in the Department of Geology, University of Colorado.

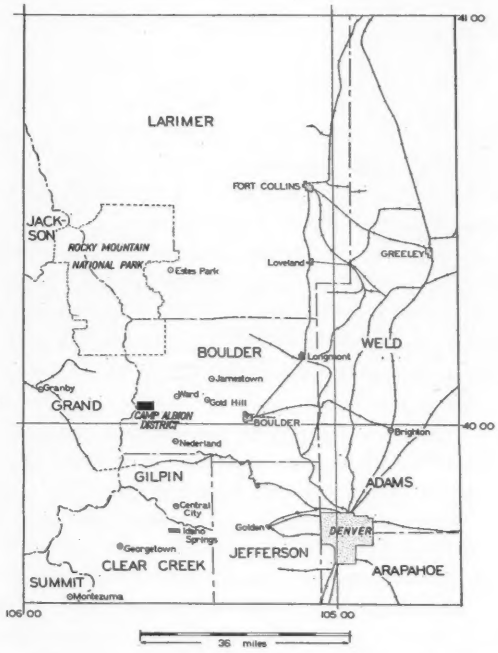


FIG. 1. Outline map of north-central Colorado showing location of Camp Albion area.

TOPOGRAPHY AND PHYSIOGRAPHY.

Camp Albion is in one of the most rugged portions of the Front Range of Colorado. The north-south crest of the continental divide lies about three miles to the west at the head of Albion Valley. The camp lies between the cliff-like walls of an easterly trending glaciated gorge; nearby Kiowa Peak rises 2000 feet above the floor of the valley, which, at Camp Albion, is about 11,000 feet above sea level.

Alpine glaciers have carved cirques and U-shaped valleys and have effectively scoured the valley floors. Thick talus cones blanket the sides of the valleys, and in the eastern part of Albion Valley large masses of glacial till conceal the bedrock.

GENERAL GEOLOGY.

The oldest rocks of the region are the schists and gneisses of the pre-Cambrian Idaho Springs formation. These rocks have been intruded lit-par-lit by granites and pegmatites of two ages. An older granite forms a part of the Boulder Creek granite-gneiss batholith, injected into the Idaho Springs formation and underlying a large part of the northern half of Boulder County. This batholith is the host rock of most of the gold telluride and ferberite deposits of Boulder County.

The Idaho Springs gneisses and the Boulder Creek granite gneiss are cut by a younger granite batholith that is locally called the Long's Peak-St. Vrain granite but is almost certainly a correlative of the Silver Plume granite of the Georgetown District and other regions to the south in the Front Range. The contacts of the Silver Plume granite are in part concordant with the flow layering and foliation of the older rocks.

All of the above rocks are intruded by a cross-cutting Tertiary monzonite stock that extends for about four miles north from Lake Albion to Mount Audubon. The stock ranges from two to two and a half miles in width and is roughly rectangular in plan. It is composed largely of monzonite but contains several differentiates ranging in composition from syenogabbro to alkalic granite. The stock locally carries abundant inclusions of all types of pre-Cambrian rocks, and it is probable that it came into place by stoping.

The ore deposits represent a late phase of the igneous activity in the stock and probably may be regarded as precipitates from the last mineralizer-rich residues of a long and complex process of igneous differentiation.

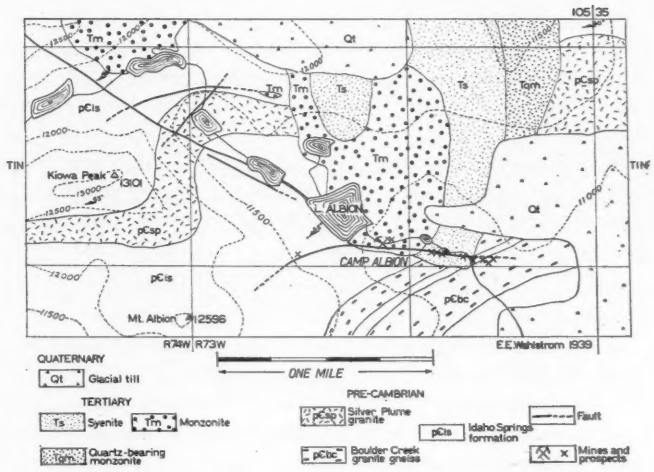


FIG. 2. Geologic map of area surrounding Lake Albion, Boulder County, Colorado.

Pre-Cambrian Rocks.

The Idaho Springs formation consists predominantly of biotite-sillimanite gneiss, but many other rock types, such as garnetiferous mica schist, biotite schist, quartzite, amphibolite, and pyroxene gneiss, are present. Locally, contact action around the periphery of the granite batholiths or the monzonite stock has resulted in the formation of irregular low grade magnetite and ilmenite deposits. The mineralogic and chemical composition of the gneisses indicates that the Idaho Springs formation originally consisted of a thick series of shales, sandstones, and impure limestones.

The Boulder Creek granite gneiss, actually a quartz monzonite, is a coarse grained porphyritic gneissoid rock containing phenocrysts of microcline and abundant biotite. In the field the rock is generally dark gray in color; locally it contains numerous black segregations of biotite, which probably represent worked over inclusions of biotite gneiss. The gneissoid structure in the rock

probably consists in part of original flow structure and in part of a foliation imposed on the rock by regional metamorphism.

The Silver Plume granite is a light gray to pinkish gray coarse-grained biotite granite. It is somewhat gneissoid and consists essentially of parallel to subparallel feldspar tablets with interstitial quartz and biotite. The gneissoid structure is original flow layering, for it can be demonstrated that near the periphery of the batholith the gneissoid structure parallels the contact between the granite and the surrounding rock.

Tertiary Rocks.

The stock extending from Lake Albion to Mount Audubon is composite and contains a series of intrusions ranging in composition from syenogabbro (oldest) through monzonite, quartz-bearing monzonite, and syenite, to granite (youngest). Camp Albion is near the southern contact of the stock and here only three types of rock are present: a coarse-grained light gray monzonite, quartz-bearing monzonite, and a light gray almost white syenite. The monzonite contains orthoclase and andesine and minor amounts of augite, hornblende, and sphene. The syenite is practically devoid of dark minerals and consists essentially of orthoclase and albite. Albite replaces the orthoclase and has almost obliterated the original granular texture, so that the rock now has a deceptive fine-grained waxy appearance.

Dikes of Tertiary quartz latite porphyry are present in the pre-Cambrian rocks. These rocks are light gray in color and contain phenocrysts of quartz and feldspar in a fine-grained groundmass.

Regional Structure.

Fig. 2 shows a geologic map of the Camp Albion region. The foliation of the schist and gneiss strikes uniformly a few degrees north of east and dips on the average about 60° N. The gneiss has been injected by concordant intrusions of pegmatite and sill-like masses of Boulder Creek granite gneiss and Long's Peak St. Vrain granite. A large sill of Silver Plume granite crosses the floor of Albion Valley about three-quarters of a mile northwest

of Lake Albion and terminates against the contact of the monzonite stock a quarter of a mile north of Lake Albion. Part of a concordant mass of Boulder Creek granite gneiss extends across the east end of Albion Valley and is lost beneath glacial till to the north and east.

The Tertiary stock cuts across all of the above structures. The flow lines and layers within the stock dip steeply outward near the contacts and indicate that the stock gradually widens with depth. The syenite is younger than the monzonite and, locally, along the contact, apophyses of syenite intrude the monzonite mass. A few small quartz latite porphyry dikes cut the pre-Cambrian rocks; it is not known whether the dikes are older or younger than the stock, but it is probable that the dikes are of Tertiary age.

Two major faults are present: one cuts the pre-Cambrian rocks in the Albion Valley just west of Lake Albion and may be traced westward to Smith Peak and terminates to the east against the Tertiary monzonite stock; the other has a southwesterly trend and cuts across the contact of the stock with the surrounding schist and gneiss. This fault is intensively mineralized in the stock and carries most of the ore deposits of the Camp Albion district. Both faults are accompanied by several subsidiary fractures.

ORE DEPOSITS.

Structure of the Veins.

The veins at Albion were formed by open space filling and by replacement of the wall rocks adjacent to the open spaces. The mineralizing solutions were guided by faults and fractures that cut monzonite and syenite in the Tertiary stock and the pre-Cambrian granite and gneiss in the area adjacent to the stock. The largest and most productive of the ore deposits was developed in the monzonite along a fault and fracture zone that is well exposed in the floor and on the south wall of Albion Valley. The fault zone intersects and offsets the gneiss and granite southwest of Lake Albion, where it is marked by a sheared and barren silicified outcrop; southeast of Lake Albion the fault zone cuts monzonite

and syenite and is characterized by a wide shear and breccia zone that gradually dies out about three-quarters of a mile east of the lake, where the fault leaves the stock and enters gneiss.

The fault zone ranges in width from a few inches in the gneiss and schist to as much as twenty feet in the syenite of the stock. The general strike is east-west, and the dip, as measured in the Snowy Range Mine, averages 60° N. The fault is attended by

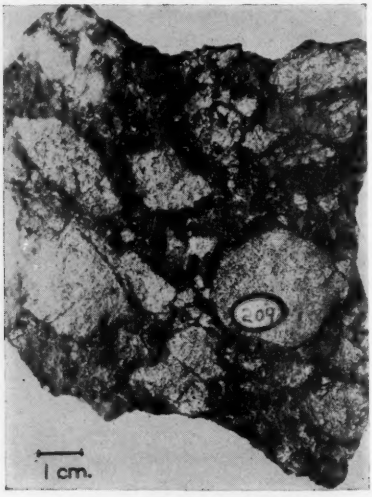


FIG. 3. Breccia from Snowy Range vein, Camp Albion. Shows rounded-to-angular fragments of syenite in a matrix of quartz and pyroxene.

numerous auxiliary fractures, which strike, on the average, about N. 60° E. Many of the fractures have been mineralized; for example, in the Eureka mine, a filled fracture forms a vein ranging from a foot to eighteen inches in width. In places the fractures accompanying the fault are closely spaced and occur as anastomosing networks of tiny fissures that have controlled the circulation of mineralizing solutions. A breccia consisting of light colored angular to rounded syenite fragments embedded in

a gray to brown matrix of sulphides and silicates is locally present as a result of the mineralization. The brecciated syenite fragments (Fig. 3) range from a fraction of an inch to three or four inches in diameter.

The ore is crudely banded and in places it has a sheeted structure occasioned by mineralization along closely-spaced parallel shear planes. In the Snowy Range Mine the vein locally consists of massive ore that shows no directional structure.

Mineralogy.

The mineralogy of the Camp Albion ore is unusual, if not unique. In the course of the laboratory investigation of the ore it was found advisable to make several chemical as well as microscopic examinations of the vein materials.

The same ore and gangue minerals are found in all of the veins at Camp Albion, but the relative amounts of the various minerals differ considerably from one vein to another and from place to place within a single vein. The gangue minerals are much more abundant than the ore minerals and constitute more than ninety-five per cent of the ore by volume.

Gangue Minerals.—The following gangue minerals, named in order of decreasing abundance, were identified in hand specimens and thin sections of the ore; diopsidic ægirite, quartz, soda asbestos, calcite, feldspar, fluorite, and sericite. Barite has been reported,[2] but the present writer has not been able to identify it in any of the ore specimens that he has examined.

Diopsidic Ægirite in coarse crystals occurs in all the veins at Camp Albion and is by far the most abundant gangue mineral. It occurs characteristically in bands or layers of sharply terminated crystals that are " frozen " to the walls of the veins and project from the vein walls toward the center. Apparently the ægirite is the first mineral that formed in the veins. Locally, cracks and joints in the country rock contain abundant interlocking pyroxene crystals alone, and it appears probable that the close intergrowth of crystals has prevented the access of later mineralizing solutions.

[2] George, R. D.: Oral communication.

In the veins the ægirite grains range from an eighth of an inch in diameter. In the Snowy Range mine pyroxene is practically the only gangue mineral and with sulphides and a little feldspar forms a vein locally attaining a width of about eight feet.

On fresh surfaces the ægirite is medium greenish gray in color and displays a fibrous to splintery fracture, which is partly controlled by an excellent prismatic cleavage. On weathered surfaces the pyroxene has a brownish to bronze color, and, in some specimens, resembles the orthorhombic pyroxene, bronzite. As a matter of fact, geologists working with the ores in former days have called the pyroxene " bronzite."

Under the microscope the pyroxene is seen to be sharply zoned and consists of two wide layers surrounded by a narrow outer layer. The zoning in the pyroxene is emphasized by quartz and carbonate that have selectively replaced the central zones to the exclusion of the outer zone.

A carefully hand-sorted sample of pyroxene was quantitatively analyzed after treatment in bromoform and dilute hydrochloric acid to remove the impurities, which consisted chiefly of quartz, calcite, and sulphides. Inasmuch as the pyroxene is zoned, the analysis gives the composition of average pyroxene and does not indicate the exact composition of any particular layer. The analysis follows:

	%	Mol. Ratio
SiO_2	49.98	.816
TiO_2	1.11	.014
Al_2O_3	8.42	.084
Fe_2O_3	15.97	.099
FeO	2.30	.032
CaO	5.48	.097
MgO	5.65	.141
Na_2O	9.17	.148
K_2O	0.61	.006
MnO	0.78	.025
H_2O (110°)	0.29	
	99.76%	

The composition, calculated from the above analysis, yields the formula (Na, Ca, K) (Fe^{III}, Al, Mg, Fe^{II}, Mn) (Si, Al, Ti)$_2O_6$.

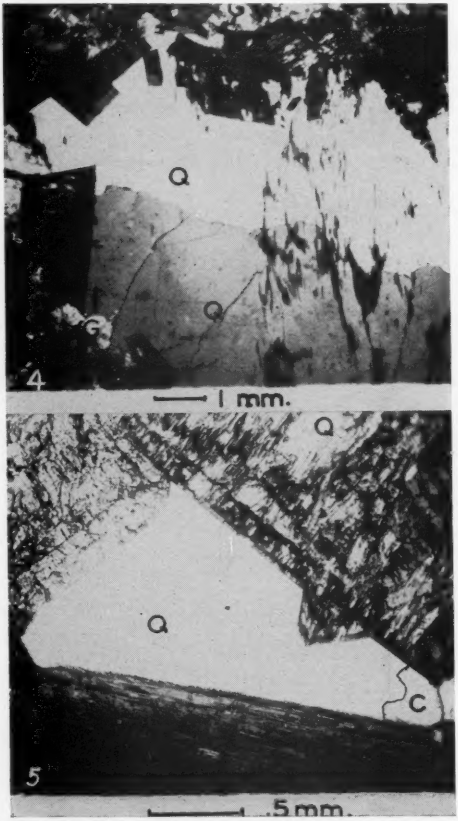


FIG. 4. Photomicrograph of thin section of breccia from Snowy Range Vein, Camp Albion. Pyroxene (dark gray) forms crystals projecting from walls of syenite (*G*) and is embedded in quartz (*Q*), which is replaced by fibrous asbestos. Plain light.

FIG. 5. Photomicrograph of thin section of ore from Snowy Range Mine. Quartz (*Q*) and calcite (*C*) fill interstices in and replace zoned pyroxene. Plain light.

The optical properties of the analyzed material, as determined in index oils and thin sections, are as follows:

$\alpha = 1.726 \pm .003$ (Na)	Monoclinic
$\beta = 1.754 \pm .003$ (Na)	Biaxial negative
$\gamma = 1.763 \pm .003$ (Na)	Birefringence .037

Optical orientation: $X \wedge c$ 28° (rim) to 35° (center)
Dispersion: strong ($\rho > v$)

The zoning is distinct, as the grains of ægirite show concentric bands which extinguish at successively smaller angles toward the exterior of each grain. Although the extinction angle changes considerably, the indices remain practically constant.

Quartz is erratically distributed throughout the veins at Camp Albion, and occurs massively or in hexagonal crystals that generally interlock and form lenticular drusy masses in the centers of the veins. Much of the crystallized quartz is embedded in later calcite and asbestos, as in the Eureka vein. Locally the quartz crystals show a peculiar color gradation from green at the bases of the crystals through gray to milky white at the terminations. A thin section of the green quartz shows the presence of a multitude of tiny prisms of minerals identified as apatite and amphibole. The amount of quartz differs considerably from vein to vein and from place to place in a single vein. The Snowy Range vein contains quartz most abundantly in the brecciated part of the vein, where massive white quartz forms lenticular masses in its center.

Soda asbestos is a characteristic mineral in both veins and wall rock of the Camp Albion ores. The mineralogy of the asbestos has been briefly described in an earlier paper,[3] but, inasmuch as the asbestos is an important gangue mineral, its description, somewhat modified, will be given here.

The vein asbestos is abundant in narrow seams paralleling the walls of the veins and in masses filling the interstices among crystallized grains of quartz and ægirite. In the Eureka Mine the asbestos occurs as tufts in the altered monzonitic wall rock and obviously formed by replacement. It is light gray and has a

[3] Wahlstrom, E. E.: An unusual occurrence of asbestos. American Mineralogist, 19: 178–180, 1934.

typical " slip fiber " structure, for the silky fibers, from a fraction of an inch to an inch long, parallel the long direction of the seams. The asbestos is generally intermixed with calcite; these minerals, with fluorite, were probably among the latest of the hypogene minerals. Thin sections show anastomosing veinlets of fibrous asbestos threaded through and replacing both calcite and quartz.

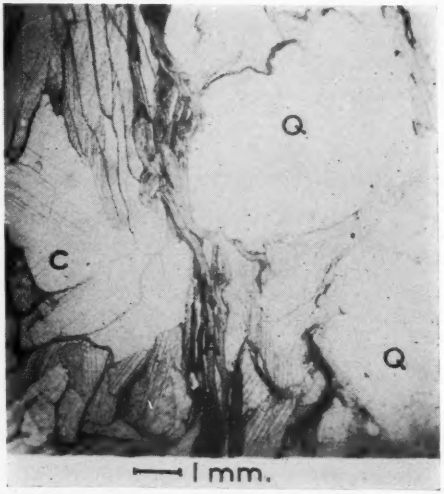


FIG. 6. Photomicrograph of thin section of gangue from vein in Eureka Mine, Camp Albion, showing quartz (*Q*), granular calcite (*C*), and veinlet of fibrous asbestos (*A*). The minerals formed in the following order: quartz (oldest), calcite, and asbestos. Plain light.

In thin sections (Fig. 6) the asbestos appears to have amphibole cleavage, but, because of the extremely small diameters of the fibers, the cleavage angles could not be accurately determined. By using an oil immersion lens, it could be seen that most of the fibers possess a flatly oval cross-section. Between crossed nicols some of the asbestos has an abnormal blue color, possibly due to the extreme fineness of the fibers. An analysis of acid-washed asbestos is given below. It is seen that the asbestos is very high

in alkalies. This observation is significant in connection with the genetic history of the Albion ore deposits.

	%	Mol. Ratio
SiO_2	56.48	0.952
TiO_2	0.30	—
Al_2O_3	1.22	0.012
Fe_2O_3	8.38	0.053
FeO	2.67	0.037
MgO	17.40	0.437
CaO	2.70	0.048
Na_2O	8.09	0.132
K_2O	1.82	0.019
H_2O	0.87	0.054
	99.93%	

Analyst: E. E. Wahlstrom

From the analysis the following composition was calculated:

$$(Na, K)_{2.5}Ca_5(Mg, Fe^{II})_4(Fe^{III}, Al)(Si, Ti)_8O_{23}(OH)$$

or, neglecting the minor oxides and multiplying by two to obtain whole numbers, the formula may be shown to be:

$$Na_5CaMg_8Fe^{III}{}_2Si_{16}O_{46}(OH)_2.$$

The mineral approximates arfvedsonite in chemical composition.

The following optical properties of the asbestos were determined in index oils and thin sections.

Monoclinic	Biaxial negative
$\alpha = 1.633 \pm .003$	Pleochroism: light and darker yellow
$\beta = 1.639 \pm .003$	Optical orientation: $Z \wedge c = 44°$
$\gamma = 1.642 \pm .003$	

White, coarse-to-fine-grained *calcite* is found in pure aggregates or intimately mixed with asbestos. The calcite generally occupies a central position in the veins and is probably one of the last minerals to be deposited. Calcite is especially abundant in the Eureka vein, where it occurs as sugary masses intermingled with silky asbestos and filling spaces between interlocking drusy quartz crystals. Some of the calcite has replaced the centers of pyroxene grains in the same manner as has the quartz.

Orthoclase in glassy anhedrons is present in a few scattered grains ranging from a fourth of an inch to an inch in diameter.

The feldspar generally fills interstices in the pyroxene and may be in part contemporaneous with it. An analysis of the feldspar is given below:

SiO_2	64.98%
TiO_2	Trace
Al_2O_3	18.26
Fe_2O_3	0.44
CaO	0.36
MgO	Trace
K_2O	14.23
Na_2O	1.42
H_2O	0.03
SrO	0.03
BaO	Trace
	99.75%

The optical properties are as follows:

$\alpha = 1.518 \pm .003$
$\beta = 1.524 \pm .003$ $\quad X \wedge c = 5°$
$\gamma = 1.526 \pm .003$ $\quad 2V$ large
Birefringence .008

Fluorite forms tiny colorless-to-purplish grains that do not exceed a sixteenth of an inch in diameter. Where found it generally appears in encrustations which lie in vugs or in porous tufts of asbestos fibers; some fluorite is associated with finely granular calcite masses.

Sericite is sparsely distributed through some specimens as tiny, colorless flakes that have replaced the peripheries of a few of the feldspar grains and may be observed only by means of a microscope.

Ore Minerals.—Argentiferous galena, pyrite, chalcopyrite, and sphalerite are found abundantly, and tetradymite, magnetite, and molybdenite sparingly in the Camp Albion ores. The abundant ore minerals occur as replacements in the wall rocks and in the veins of all the Camp Albion deposits, but differ in relative proportions from one vein to another. Impure chalcocite is a supergene mineral found in small amounts in the ore close beneath the slightly altered surface exposures of some of the veins. Carbonates and oxides of the metals are present in the oxidized zone of the veins, but are relatively unimportant.

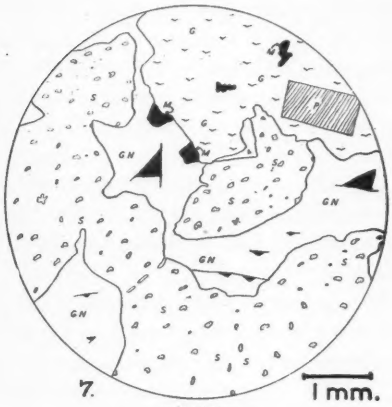
The *galena* shows either octahedral parting or cubical cleavage or both, depending on its occurrence and association with the gangue minerals. The parting results from the splitting of the galena along exsolved tetradymite plates, which have developed parallel to the octahedral directions in the crystals. The mineralogy of the galena has been described at length in a previous paper by the writer.[4] In the Snowy Range vein the octahedral galena appears in the interstices of coarsely crystalline ægirite grains. In the Eureka vein the galena is octahedral where it has formed in pyroxene, but where it is disseminated through sugary calcite in the middle of the vein, it shows either cubical cleavage or octahedral parting, or both. Galena replacing the monzonite in the wall rock of the veins generally has cubical cleavage.

Pyrite is present in small euhedral grains that have replaced the pyroxene in the veins and the rocks in the walls of the veins, and in small brecciated and corroded grains in chalcopyrite. The replacing pyrite is found in both monzonite and pre-Cambrian gneiss, as, for example, in the Monarch shaft. The fractures in monzonite at the sides of the Snowy Range vein are locally encrusted with pyrite grains.

Chalcopyrite is erratically distributed through the veins and generally forms crudely lenticular masses close to and paralleling the walls of the veins. Some masses of chalcopyrite fill spaces between euhedral grains of ægirite and, accordingly, are very irregular in outline. The chalcopyrite is commonly associated with sphalerite and either includes fragments of it or forms dots or blebs scattered uniformly through it. Contacts between the sphalerite and chalcopyrite are smooth and may be described as "mutual." It is probable that the period of deposition of the chalcopyrite over-lapped that of the sphalerite. Dots of chalcopyrite in the sphalerite may have originated by exsolution, and if this is so, are younger than the sphalerite.

Sphalerite is present in separate grains or in masses associated with galena or chalcopyrite. It is probable that these ore min-

[4] Wahlstrom, E. E.: Octahedral parting on galena from Boulder County, Colorado. American Mineralogist, *22*: 906–911, 1937.



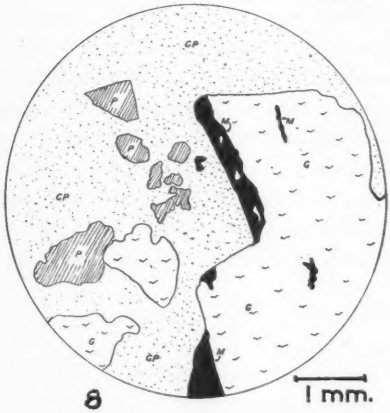


FIG. 7. Camera lucida drawing of polished section of ore from Snowy Range Mine, Camp Albion, showing gangue (*G*), magnetite (*M*), pyrite (*P*), sphalerite (*S*), with small blebs of chalcopyrite, and galena (*GN*). Black triangular areas represent pits whose sides parallel the octahedral directions in galena.

FIG. 8. Camera lucida drawing of ore from Eureka Mine, Camp Albion, showing magnetite (*M*) bordering and included within euhedral pyroxene (*G*). Corroded pyrite cubes (*P*) are embedded in chalcopyrite (*CP*).

erals developed by replacement of older interstitial quartz or calcite.

Anhedral *magnetite* is found as interstitial fillings in pyroxene and as irregular aggregates replacing the rims, and, to a lesser extent, the interiors of the pyroxene grains. The magnetite generally contains inclusions of silicates.

A few small flakes of *molybdenite* are found in cracks and joints in the monzonite adjacent to the Snowy Range vein. No molybdenite was observed in the polished sections of the ores from the veins themselves.

Small amounts of impure *chalcocite* were observed in polished sections of ore collected near the outcrop of the vein. Inasmuch as the veins at the exposures show signs of having been somewhat altered by weathering agents, and chalcocite is absent from the deep ores, it follows that the chalcocite is supergene. It has replaced galena in preference to the other ore minerals and occurs around the borders of the galena grains or in veinlets that follow octahedral parting cracks in the galena. The chalcocite is blue gray and when examined with polarized light is seen to contain numerous small blades and patches of covellite. Locally the chalcocite has a faint brownish tinge, explained, probably, by the presence of small amounts of bornite or limonite. Bornite, as such, was not found in any of the polished sections that were examined.

PARAGENESIS.

The Camp Albion ore deposits are genetically related to the rocks of the Audubon-Albion monzonite stock and represent one of the last events in its long and complex igneous history. A study of the stock shows that it consists of a succession of intrusions each of which is more alkaline and siliceous than the one it follows. Inasmuch as the Camp Albion ores are found only in or near the rocks of the stock and are composed of highly alkaline and siliceous ores, it follows that the ores form an integral part of its igneous history. Moreover, the veins of the ore deposits cut the youngest igneous rock of the stock, an alkaline granite

and, therefore, probably were formed as a last dying effort on the part of deep-seated igneous processes at work in the stock.

The succession of rocks in the stock is as follows: syenogabbro (oldest), monzonite, quartz-bearing monzonite, syenite and quartz-bearing syenite, alkaline granite, and, finally, siliceous alkaline ore. From an examination of thin sections of the rocks it is seen that not only did the younger magmas become increasingly more alkaline and siliceous, but also more highly charged with fluids, for the younger rocks show evidences of alteration and replacement of a type that is especially pronounced in the presence of fluids. For example, the orthoclase of the syenite and alkalic granite is abundantly replaced by albite, and the syenite in places contains an abundance of secondary zeolite, a hydrous mineral. Probably then, the ore deposits were deposited from special concentrations of highly fluid siliceous alkaline solutions, which accumulated at depth as the final residues from a long period of igneous differentiation, injection and crystallization in a monzonitic magma.

The igneous processes culminated in the formation of ore-bearing solutions, which were unquestionably alkaline at the outset of the period of vein formation as shown by an abundant deposition of soda pyroxene. Moreover, it can be demonstrated that the solutions remained alkaline throughout the entire period of mineralization, for soda asbestos was one of the last minerals to form in the veins.

The sequence of gangue minerals, as determined from a study of thin sections and hand specimens of vein materials, is as follows: diopsidic ægirite (oldest), alkalic feldspar, quartz, calcite, soda asbestos, and fluorite.

The succession of ore minerals as determined in a study of polished sections and hand specimens of the ores, is as follows: magnetite (oldest), pyrite, molybdenite (?), sphalerite and chalcopyrite, galena, and tetradymite. Chalcocite and covellite are supergene. All of the hypogene ore minerals are found as replacements in the wall rocks of the veins as well as in the veins themselves. Molybdenite was observed chiefly in the wall rocks, where it occurs along minute fractures in altered monzonite. The

succession of ore minerals in the wall rocks is the same as that in the veins.

The succession of both ore and gangue minerals is shown in the accompanying diagram. The succession of either gangue minerals

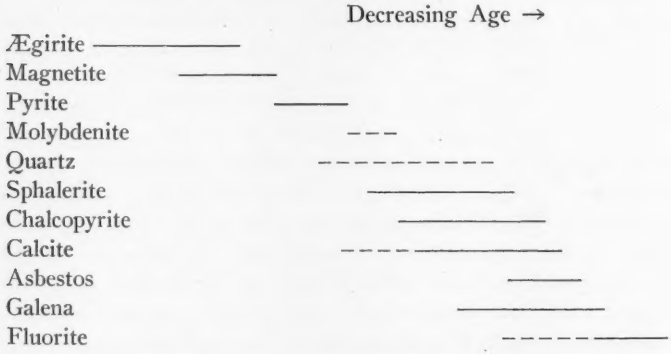


FIG. 9. Paragenetic diagram. Camp Albion ores. Dashed lines indicate minerals of doubtful position in the sequence.

or ore minerals is determined with some confidence, but the interrelations of the two sequences is not clearly demonstrable. The diagram, then, is accurate for either gangue or minerals alone, but may not indicate the exact positions of certain minerals in the complete sequence. The positions of minerals of doubtful relations are indicated by dotted lines.

WALL ROCK ALTERATION.

All of the ore and gangue minerals have replaced the wall rocks. In thin sections the replacing minerals are seen to cut sharply across all of the minerals in the monzonite and syenite and do not seem to favor any particular mineral as a host. Some thin sections of monzonite and syenite contain evidences of "saussuritization," a type of alteration that might be thought to be related to the ore-bearing solutions. However, the alteration products, which consist of a mixture of zeolite, carbonate, chlorite, and seri-

cite are uniformly distributed through all the quartz-free rocks of the stock, and, therefore, are not directly related to the mineralizing solutions localized along the veins, but, rather, to other processes which were active in the late magmatic stages of the history of the stock.

GENETIC CLASSIFICATION.

To the writer's knowledge, the literature of ore deposits does not contain a description of a deposit similar to that at Camp Albion. Accordingly, any genetic classification must be based on the characteristics of a deposit that is unusual in its mineral assemblage, and structurally unlike deposits of conceivably similar origin.

To classify the deposit, the mineralogy and the structure of the veins were given consideration. The mineral association of dominant soda-pyroxene, soda-asbestos, and massive coarsely-crystallized quartz, is undoubtedly suggestive of a hypothermal ore. The presence of magnetite and molybdenite does not detract from, but rather confirms, this genetic classification. Pyrite, chalcopyrite, sphalerite, and calcite are ubiquitous or persistent minerals and are, by themselves, of no particular significance. The presence of pure potash feldspar and fluorite is not easily explained, for these are more at home in mesothermal and epithermal deposits.

The temperature range of stability of the ore and gangue minerals, in the light of present knowledge, is not satisfactorily determinable, but the classification of the deposit as a "high" or "medium" temperature deposit would probably pass unchallenged. Pyroxene, according to Lindgren,[5] is considered to be stable at high temperatures (above 550° C.), but the influence of volatiles and other solutes is not yet quantitatively estimable. Polished and etched quartz from the Camp Albion veins do not show the complex twinning and fracturing that characterize quartz which has undergone inversion from high to low quartz; so it seems likely that the maximum temperature lay somewhat

[5] Lindgren, W.: Mineral Deposits, 4th Ed. McGraw-Hill Book Co., 1933.

below the inversion temperature of quartz.[6] Moreover, in the presence of water vapor, alkalies, and fluorine, it is possible that the lower limit of the temperature range may have been as low as 250° C.

An alternative suggestion that must be considered is the possibility that the mineral assemblage is actually mesothermal. It seems likely that the soda-pyroxene and soda asbestos may have developed at considerably lower temperatures than are believed to exist during the periods of formation of soda-free pyroxene (augite) and soda-free asbestos (anthophyllite, tremolite, *et al*). If this is so, the feldspar, calcite, fluorite, and all of the sulphides would be compatible with the observed vein structures.

The structures of the veins are typically mesothermal. Lindgren [7] says of mesothermal veins, "The fissures are fairly regular in strike and dip, having neither the extreme brecciated structure common to deposits formed close to the surface nor the lenticular form and irregular openings of the deep-seated deposits." And Graton [8] states, "the mesothermal zone shows . . . somewhat more of vugginess, occasional crude and coarse banding in the veins, and marginal rock alteration that is more readily identifiable as such." (Comparison with hypothermal ores.) All of the features enumerated above are readily seen in the Camp Albion ores, and it is this fact, coupled with the presumably hypothermal mineralogy of the ore, which places the deposit in an anomalous position in the depth-temperature classification. In other words, the deposit partakes of features classified according to the mineralogy as definitely hypothermal, and according to the structure as characteristically mesothermal.

An estimate of the depth of formation of the ores is fraught with uncertainty and conjecture, but it seems probable that the depth was of the order of 10,000 feet beneath the surface existing

[6] The inversion temperature of quartz is commonly stated to be 573° C., but it must be borne in mind that pressure substantially increases the inversion point. For example, Gibson (1928) determined that at a depth of ten kilometers quartz inverts at 644° C. The limit of the upper range of temperature of ore deposition thus cannot be established unless the depth of formation is accurately known.

[7] Lindgren, W.: op. cit., p. 530.

[8] Graton, L. C.: The depth zones in ore deposition. ECON. GEOL., 28: 535, 1933.

at the time of ore deposition. In this estimate several factors were considered, among which are the following: structure of the veins, chilled contacts of the genetically associated stock, and the physiographic and geologic history of the region.

According to Lindgren the mesothermal veins formed at depths ranging from 4,000 to 12,000 feet. Graton believes that the range is much greater and cites many examples of deposits that show remarkably little change over great vertical spans, from which he concludes that a vertical range of 20,000 feet does not seem unreasonable. Of considerable significance in the present problem is the observation that the monzonite stock, with which the ores are associated, has chilled fine-grained to porphyritic contacts, a fact which seems to indicate that the country rocks did not possess the temperatures characteristic of great depths. Moreover a consideration of the physiographic and geologic history of the region suggests that the exposed portion of the vein formed under a cover of sediments and igneous rocks which probably did not much exceed 15,000 feet.

Buddington [9] has coined the word " xenothermal " to be applied to high temperature fissure fillings and replacements formed at shallow depths. None of the examples he cites resembles the Camp Albion deposit, but it is quite possible that the ores here are deep xenothermal in the sense of Buddington's definition.

CONCLUSIONS AND SUMMARY.

The Camp Albion ores consist of argentiferous galena, tetradymite, pyrite, chalcopyrite, sphalerite, magnetite, and molybdenite in a gangue consisting of soda pyroxene, soda asbestos, coarsely crystalline quartz, calcite, feldspar, and fluorite. The ore forms veins, breccia fillings, and irregular wall rock replacements in and along a shear zone cutting the contact between a genetically related Tertiary monzonite stock and pre-Cambrian schists and gneisses. The mineralogy is suggestive of deep-seated or hypothermal conditions, but the structure is typical of shallow meso-

[9] Buddington, A. F.: High-temperature mineral associations at shallow to moderate depths. ECON. GEOL., 30: 205–222, 1935.

thermal deposits. However, the presence of abundant soda, water, and fluorine in the ore solutions may have lowered the stability range of the ore and gangue minerals to such an extent that the minerals were precipitated within the normal temperature range of mesothermal deposits. If this is so, the mineralogy and structure are not out of harmony, and the ores can be regarded as mesothermal. It is possible that the ore might be classified as deep xenothermal.

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MINOR ELEMENTS IN SPHALERITE.

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ABSTRACT.

New spectrographic analyses and previously published information provided data concerning elements present in sphalerite in minor amounts. The variation in minor element content is correlated with the type of mineral deposit in which the sphalerite occurs. Antimony, mercury, thallium, and arsenic are largely restricted to sphalerite from mineral deposits commonly considered to have formed at low temperatures. Other elements are widely distributed in sphalerite from many types of deposits. The manganese concentration is greatest in sphalerite from high temperature occurrences, indium in that from mesothermal deposits, and gallium and germanium increase with decreasing temperature of deposition. High concentrations of cadmium and tin seem most likely to occur in sphalerite from deposits of other than low temperature type. Mississippi Valley deposits, European zinc ores of Mississippi Valley type, and barite deposits of Central Kentucky are all of low temperature origin. Sphalerite from each of these metallogenetic regions contains minor elements of distinctive kind and amount.

The minor element content of sphalerite can be related not only to the temperature at which the sphalerite is formed, but also, and perhaps in large part, to the chemical character of the ore-bearing solutions of each metallogenetic province.

INTRODUCTION.

Most minerals contain, in addition to the major constituents, other elements in minor quantities, generally less than one per cent. Many different minor elements are known to be commonly present in sphalerite [1] although most investigations of these elements such as the work of Vernadsky [2] and Goldschmidt [3] have been incidental to a study of their distribution in the earth's crust.

That minor elements may reflect the genesis of the sphalerite in which they are contained is of equal geological significance.

[1] Doelter, C.: Handbuch der Mineralchemie, 4, pt. 1: 307–313.

[2] Vernadsky, W.: Bull. Acad. Imp. Sci. St. Petersburg, 4: 1129–1148, 1910; 5: 187–193, 1911.

[3] Goldschmidt, V. M. and Peters, Cl.: Nachr. Ges. Wiss. Göttingen, Math. Phys. Kl., pp. 152–153, 1933.

De Launay and Urbain [4] have suggested that the minor element content of sphalerite is related to the depth of vein formation, the sphalerite texture, and the metallogenetic province from which the sphalerite comes. Goldschmidt and Peters,[5] Graton and Harcourt,[6] and Tornquist,[7] have related their observations concerning minor elements in sphalerite to temperature or intensity conditions of vein formation. Graton and Harcourt have emphasized the similarity of the minor element content of sphalerite in ores of magmatic origin and in those of Mississippi Valley type. They interpret this as evidence of magmatic origin of the Mississippi Valley type deposits.

This study is concerned with the possible general relationships between the minor elements present in sphalerite and the geology of the sphalerite occurrence. The data used consist of new spectrographic analyses of minor elements in 75 sphalerite samples from many varied localities. Minor element content in sphalerite is considered in relation to two features of the mineral occurrence that are of genetic significance: the type of mineral deposit defined on the basis of temperature, and the metallogenetic group to which the deposit is related. This study suggests some new relationships between minor element content and temperature and has corroborated most of the conclusions of previous workers. Conclusions from the new data emphasize that the minor element content of sphalerite is characteristic not only of the vein formation temperature but also of the metallogenetic province in which the sphalerite occurs.

ACKNOWLEDGMENTS.

The writer wishes to express his appreciation to Prof. G. R. Harrison, Director of the Research Laboratory of Experimental Physics, Massachusetts Institute of Technology, who allowed the use of a grating spectrograph for the analytical determinations

[4] De Launay, L. and Urbain, G.: Bull. Geol. Soc. France, 4th ser., 10: 787–795, 1912.

[5] Goldschmidt, V. M. and Peters, Cl.: *op. cit.*, 1933.

[6] Graton, L. C. and Harcourt G. A.: ECON. GEOL., 30: 800–824, 1935.

[7] Tornquist, A.: Geol. Bundesanstalt, Wien, Verh., pp. 197–202, 1930.

and to Prof. W. H. Newhouse of the Department of Geology, Massachusetts Institute of Technology, for his many helpful suggestions and interest in the problem.

METHOD OF ANALYSIS.

Analyses of sphalerite from localities chosen with regard to geological diversity are listed in Table I. The material for analysis was selected under a binocular microscope after polished section study had indicated that the sphalerite could thus be freed from other material. Samples were powdered and mixed with ammonium sulphate free from spectroscopic impurities. A crater in the lower (positive) electrode of highest purity graphite was filled with the sample mixture. Arc spectra of the sphalerite were recorded on Eastman " 40 " plates using a twenty-one foot grating spectrograph, Paschen mounting, with dispersion in the first order of approximately 2.5 Angstroms per mm. Comparison with known spectra determined the qualitative presence of minor elements. Comparison with spectra of ratio powders which contain known quantities of zinc oxide in an ammonium sulphate base fixed the order of magnitude of cadmium, manganese, germanium, gallium, indium, tin and thallium. Minor quantities of lead, copper, iron and silver were not reported because of possible slight contamination of the sample by minerals containing these elements in major amounts.

DISCUSSION OF THE DATA.

Reference to Table I shows that the specimens analyzed commonly contained cadmium, manganese, gallium, germanium, indium, cobalt, nickel and tin, and that bismuth, thallium, arsenic, and molybdenum were less often detected. Mercury has been reported in sphalerite by other investigators,[8] and chromium,[9] palladium,[10] vanadium,[11] and titanium [12] have each been reported in

[8] De Launay, L. and Urbain, G.: *op. cit.* Soltsien, P.: Arch. Pharm., *24*: 800, 1886, referred to in Doelter, C., *op. cit.*, p. 313.

[9] Hartley, W. N. and Ramage, H.: Jour. Chem. Soc., Trans., *71*: 540, 1897.

[10] Claussen, G. E.: Am. Min., *19*: *223*, 1934.

[11] Moritz, H.: Neues Jahrb. Beil. Bd. 67A: 130, 1933.

[12] Claussen, G. E.: *op. cit.*, p. *223*, 1934.

TABLE I.

ANALYSES OF SPHALERITE.

No.	Locality	Cd	Mn	Ge	Ga	In	Sn	Tl	Co	Ni	Bi	Mo	As
	Low Temperature Deposits:												
1	Joplin, Mo.	—	–	—	–								
2	Carterville, Mo., "Ruby Blende" on No. 6	—		—	–								
3	Jasper County, Mo., "Ruby Blende" on No. 7	—		—	–								
4	Granby, Mo., Deposited 110°–115°	—		–	—								
5	Empire, Kansas	—	–	–	—				+	+			
6	Carterville, Mo., Alexandra Mine	—	–	–	–				+	+			
7	Jasper County, Mo., Hastings Mine	—	–	–	–				+	+			
8	Chitwood, Mo., King Jack Mine	—		–	—				+	+			
9	Carterville, Mo., Alexandra Mine	—		–	—				+	+			
10	Hazel Green, Wis., Badger Mine	—	–	–	–								
11	Southeastern Mo., Deposited 105°–125°	—		—	—	–			+				
12	Rush, Arkansas, Morning Star Mine	—		–	—				+	+			
13	Gt. Slave Lake N. W. T., Lead Zinc Claims	—	–	–									
14	Upper Silesia, Bleischarly Mine	—	–	–				—					+
15	Stolberg-Aachen, Diepenlinchen Mine	—	–	–				—					
16	Welkenraedt, Moresnet region	—	–	—				—					+
17	Iserlohn, Westphalia	—	–	—				—					
18	Raibl, Italy	—		–				—					+
19	Tazewell, Tenn., New Prospect Mine	—	–	–	—					+			
20	Mascot, Tenn.	—		–	–								
21	Austinville, Va.	—	–	–						+			
22	Friedensville, Pa.	—	–	–	—		–						
23	Danville, Ky., Boone Creek Vein	—		–	—	–							
24	Boyle County, Ky., Deposited 70°–90° C.	—		–	—								
25	Henry County, Ky., Lockport Vein	—		–	—								
26	Franklin County, Ky., Clark Vein	—		—	—	–							
27	Duval Station, Ky., Wm. Davis Vein	—		—	—	–							
28	Marion, Ky., Columbia Mine	—	–	—	—		–		+				
29	Hatfield, Mass., Old Lead Mine	—	–	–	—				+				
30	New Galena, Pa., Deposited 160°–165°	—	–	–	–		–						
31	Phoenixville, Pa., Wheatley Mine	—		—	—	–	—						
32	Rossie, N. Y., Victoria Mine	—	–	–	—	–	—		+				
33	Cumberland, England	—		—	–	–			+	+			
34	Ouray, Colo., Governor Mine	—	–		–								
35	Ouray, Colo., Camp Bird Mine	—	–			–			+				
36	Telluride, Colo., Black Bear Mine	—	—		–	–			+		+		
37	Cusihuiachic, Mex., Light green color	—	—						+	+			
38	Cusihuiachic, Mex., Yellow-brown color	—	—										
39	Premier Mine, B. C.	—	—										

TABLE I.—*Continued*

No.	Locality	Cd	Mn	Ge	Ga	In	Sn	Tl	Co	Ni	Bi	Mo	As
	Intermediate Temperature Deposits:												
40	Goldenville, N. S., Royal Oak Mine	——	–			—							
41	Bingham Canyon, Utah, Utah Apex Mine	——	—		–		—						
42	Bingham Canyon, Utah	——	—		–	—	—						
43	Ophir, Calif., St. Patrick's Mine	——	–		–	–				+	+		
44	Quiruvilca, Peru	——	–		–	–	—						
45	Park City, Utah, Daly Judge Mine	——	—		–	–	–						
46	Ice River, B. C., Waterloo Claim	——	—		–	—	—				+		
47	Cherryfield, Maine	——	—			–			+		+		
48	West Pembroke, Me., Pembroke Prospect	——	—			–			+				
49	Georgetown, Colo., "7–30" Mine	——	–		–	–	–		+	+			
50	Georgetown, Colo., Brown Vein	——	—			—			+	+	+		
51	Georgetown, Colo., Terrible No. 2 Vein	——	–		–		—		+	+			
52	Caribou, Colo.	——	—		–	–	—		+	+			
53	Nevada City, Colo., Jones Lode	——	—			—							
54	Nevada City, Colo., Kansas Lode	——	—	–	–	—					+		
55	Leadville, Colo., Tuscon Mine	——	nd	–	–	——	—						
56	Pioche, Nevada, Combined Metals Mine	——	nd	–	–	–	——			+			
57	Couer d'Alene, Idaho, Interstate Callahan	——	–	–	–	–	—						
58	Shafter, Texas	——	–	–	–	–			+	+			
59	Silver Islet, Ont.	——	–	–	—	–			nd	nd		+	nd
60	Shasta County, Cal., Mammoth District	——	—	–	—	—				+		+	
61	Lauthenthal, Germany	——	——			—	–						
62	Freiburg, Germany	——	——			——	—						
63	Hermosa, New Mexico, Ocean Wave Mine	——	–		–				+				
	High Temperature Deposits:												
64	Ammeberg, Sweden	—	——			—			+	+			
65	Dannemora, Sweden, South Section	——	–	–									
66	Balmat, New York, Primary Ore	——	—		–	–							
67	Edwards, New York	—	——	–	–	–	—						
68	Warren, New Hampshire	——	——		–	—							
69	Mineral, Virginia, Holladay Mine	——	——		–	–	—			+			
70	Charlemont, Mass.	——	——	–		–							
71	Alotepeque, Guatamala	——	—						+	+			
72	Santa Barbara, Mexico, Tecolotes Mine	——	—						+				
73	Pike Hill, Vermont	——	——		–	–			+				
74	Broken Hill, N. S. W.	——	——			–	——		+	+			
75	Cornwall, England	——	—			—	——				+		

Key to symbols: —— = >1%. + = present.
— = .1–1%. nd = not determined.
— = .01–.1%. Not detected if not otherwise indicated.
– = <.01%.

sphalerite from one or two localities. Several other elements found in sphalerite have not been considered in the present study. These include copper, iron, lead, silver, and antimony,[13] which occur presumably in solid solution in sphalerite, and also the elements found in fluid inclusions: sodium, calcium, potassium, and lithium.[14]

In addition to the variation in kind of minor constituents found in sphalerite there is also a wide variation in the amount of each element. These variations in kind and amount of the minor elements in different sphalerite samples might be related to such features of the geology of the sphalerite deposit as temperature of formation, metallogenetic group to which the deposit belongs, type of wallrock, or to such mineralogical characteristics as texture and crystal habit of the sphalerite. This paper attempts to relate the new data presented in Table I to only two of these genetic factors of sphalerite formation—the temperature type of the deposit, and the metallogenetic group to which the deposit belongs.

Relation of Minor Element Concentration to Temperature.

The analyses of Table I are divided into three groups, the three temperature types of deposits, according to Lindgren's classification[15] represented by the analyzed sphalerite. In addition, temperature determinations on fluid inclusions which have been made by Newhouse[16] provide evidence of the temperature of formation of several of the specimens. These, together with a new determination by the writer, are noted in Table I.

Analyses numbers 1–39 are from low temperature deposits. This group includes the lead-zinc deposits in sedimentary rocks of Mississippi Valley type, analyses numbers 1–22; galena-sphalerite-carbonate veins commonly with barite or fluorite and which are

[13] Graton, L. C. and Harcourt, G. A.: *op. cit.*, p. 803, 1935. Moritz, H.: *op. cit.*, 1933.

[14] Newhouse, W. H.: Econ. Geol., 27: 430–431, 1932. Llord y Gamboa, R.: Annal. Soc. Esp. Fis. Quim., pp. 413–421, 1910.

[15] Lindgren, W.: Mineral Deposits, 4th Ed., 1933.

[16] Newhouse, W. H.: Econ. Geol., 28: 748, 1933.

of low temperature origin, analyses numbers 23–33; and epithermal deposits, analyses numbers 34–39. Analyses numbers 40–63 make up the second group. They are of sphalerite from mesothermal deposits, formed at intermediate temperatures. The third group of analyses, numbers 64–75, are from high temperature deposits, the hypothermal and pyrometasomatic deposits of Lindgren.

Consideration of the new data and of that already published suggests that the occurrence of some minor elements is largely restricted to sphalerite from a single temperature type of deposit. Arsenic and thallium are reported in the new analyses only from low temperature sphalerite. Others have also found arsenic [17] and thallium [18] chiefly in sphalerite from low temperature deposits. The occurrence of antimony and mercury in low temperature deposits was noted by De Launay and Urbain.[19] They found that both elements were characteristic of sphalerite from shallow-seated Tertiary deposits of the Mediterranean region. Mercury was not detected by De Launay and Urbain in other sphalerite, and antimony was only rarely found by them in sphalerite from deep-seated deposits. These observations suggest that the elements antimony, mercury, thallium, and arsenic where present in sphalerite are almost wholly restricted to that from low temperature deposits.

Molybdenum is reported in only two of the new analyses. Both are from deposits of intermediate temperature type, as is the deposit at Tsumeb, S.W. Africa, where molybdenum has been found in the sphalerite by Moritz.[20] Molybdenum has been found in other sphalerite [21] but the localities have not been reported. More data might show a wider distribution but where molybdenum has

[17] Claussen, G. E.: *op. cit.*, 1934. Tornquist, A.: *op. cit.*, 1930. Stappenbeck, R.: Archiv. Lagerstättenforsch. Preuss. Geol. Landes., 41: 86, 1928. Schneiderhöhn, H.: Chemie der Erde, 5: 391, 1930.

[18] Von Kobell, F.: Jour. Prakt. Chem., 3: 176, 1871. Hartley, W. N. and Ramage, H.: *op. cit.*, 1897. Rimatori, C.: Rend. R. Accad. Lincei, Cl. Sci. Fis. Mat. Nat., Ser. 5, 14: 688–696, 1905.

[19] De Launay, L. and Urbain, G.: *op. cit.*, 1910.

[20] Moritz, H.: *op. cit.*, 1933.

[21] Urbain, G.: Compte Rendu., 149: 603, 1909.

been reported from sphalerite and the geology is known, the deposits are of intermediate temperature type.

Cadmium, manganese, gallium, germanium, indium, cobalt, tin and nickel occur in sphalerite from deposits of all three temperature types. The quantity of these elements, expressed in the new analyses as an order of magnitude, varies within wide limits. In order to test the relationship between the temperature type of the deposit and the order of magnitude of the elements contained in the sphalerite, data for six of the elements were taken from the 75 new analyses and treated from a statistical point of view in Table II. Here is recorded for each of these elements the number of times that each concentration occurs in sphalerite from high, intermediate, and low temperature deposits, in columns 3, 5, and 7. These same data are expressed as percentages in columns 4, 6, and 8. The percentages are shown diagrammatically in Figs. 1–6. The frequency of occurrence in 75 analyses of each order of magnitude of an element in sphalerite from high, intermediate, and low temperature deposits is indicated by the height of each patterned area.

Fig. 1 illustrates the relationship of manganese concentration in sphalerite to the temperature type of deposit. Most sphalerite from hypothermal and pyrometasomatic deposits contains .1–1 per cent manganese, most mesothermal sphalerite .01–.1 per cent manganese, and sphalerite from low temperatures deposits less than .01 per cent manganese. De Launay and Urbain have noted [22] that manganese was almost always present in sphalerite from deep-seated deposits. This is in agreement with data in Fig. 1, which shows that the manganese content of sphalerite becomes higher in general in ore deposits formed at successively higher temperatures.

The variation in order of magnitude of indium in sphalerite is illustrated in Fig. 2. Indium was not detected in more than three-quarters of the specimens of low temperature sphalerite analyzed. Published analyses also suggest that low temperature sphalerite contains a low indium concentration. Analyses of three sphalerites from epithermal veins in Japan reported less than .003 per

[22] De Launay, L. and Urbain, G.: *op. cit.*, 1910.

TABLE II.

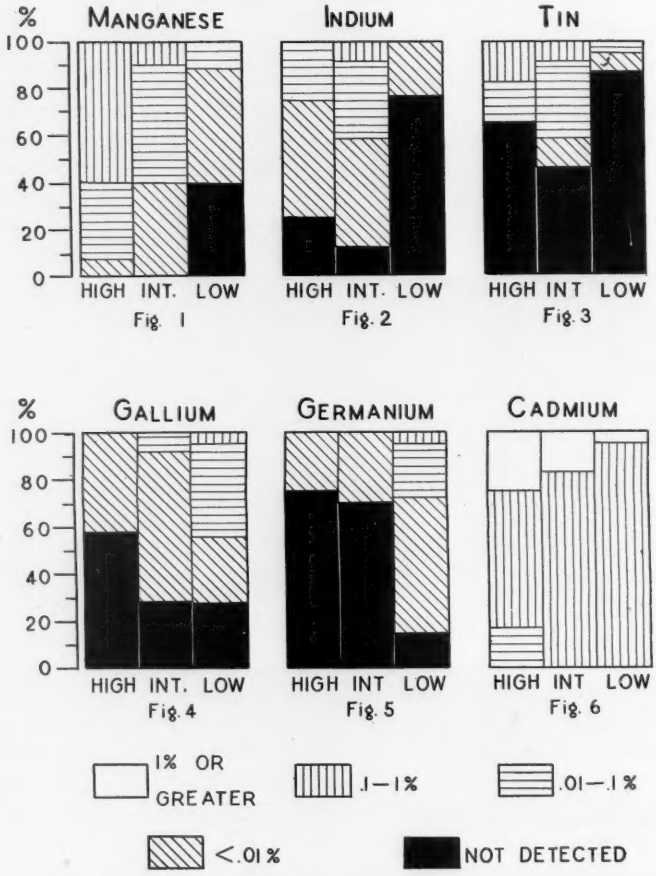
DISTRIBUTION OF MINOR ELEMENT CONCENTRATION IN SPHALERITE
(*Data from Table I.*)

Element	Concentration	Temperature Type of Deposit					
		High		Intermediate		Low	
		No. of Analyses.	% of Analyses.	No. of Analyses.	% of Analyses.	No. of Analyses.	% of Analyses.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Manganese	.1–1%	7	59	2	9	0	0
	.01–.1%	4	33	11	50	4	10
	<.01%	1	8	9	41	19	49
	Not detected	0	0	0	0	16	41
Indium	.1–1%	0	0	2	8	0	0
	.01–.1%	3	25	8	33	0	0
	<.01%	6	50	11	46	9	23
	Not detected	3	25	3	13	30	77
Tin	.1–1%	2	17	2	8	0	0
	.01–.1%	2	17	8	33	2	5
	<.01%	0	0	3	13	3	8
	Not detected	8	66	11	46	34	87
Gallium	.1–1%	0	0	0	0	2	5
	.01–.1%	0	0	2	8	15	39
	<.01%	5	42	15	63	11	28
	Not detected	7	58	7	29	11	28
Germanium	.1–1%	0	0	0	0	2	5
	.01–.1%	0	0	0	0	9	23
	<.01%	3	25	7	29	22	57
	Not detected	9	75	17	71	6	15
Cadmium	1% or greater	3	25	4	17	2	5
	.1–1%	7	58	20	83	37	95
	.01–.1%	2	17	0	0	0	0
	<.01%	0	0	0	0	0	0
	Not detected	0	0	0	0	0	0

cent indium,[23] and sphalerite from Montevecchio, Sardinia, contained .007–.012 per cent indium.[24] A wide variation in indium concentration in sphalerite from mesothermal and high temperature deposits is indicated in Fig. 2. Two extremes of concentration have been reported by others from mesothermal occurrences:

[23] Imaizumi, Y.: Jour. Chem. Soc. Japan, 54: 1009, 1933.

[24] Cambi, S. C. L. and Malatesta, L.: Rend. R. Inst. Lombardo Sci. Lett. Milano, ser. 2, 69: 372, 1936.



FIGS. 1–6. Relation of minor element concentration in sphalerite to high, intermediate, and low temperature types of mineral deposits.

no indium in sphalerite from Tsumeb, South West Africa,[25] and .1231 per cent indium in sphalerite from a mesothermal deposit in Sardinia.[26] De Launay and Urbain [27] found that indium was always present in sphalerite from deep-seated deposits and Vernadsky [28] noted that indium occurred in older sphalerite. These data and the new information in Fig. 2 suggest that the concentration of indium is least in sphalerite from low temperature deposits, is greater in that from both high and intermediate temperature deposits and is most often greatest in sphalerite from mesothermal occurrences.

Tin was detected in less than one-third of the samples of sphalerite analyzed. This is shown by the large black areas in Fig. 3. It was most often detected in sphalerite from high and intermediate deposits. Sphalerite from Bolivian and English mesothermal and hypothermal tin veins contains unmixed stannite [29] thus indicating that tin was present in solid solution in the sphalerite at the time of its formation. De Launay and Urbain [30] found tin commonly present in sphalerite from deposits of deep-seated character. It may be concluded that tin is more often detected and is present in larger amounts in sphalerite from deposits of intermediate and high temperature type than in low temperature sphalerite.

Fig. 4 shows the relationship between temperature type of deposit and gallium content of sphalerite. The concentration of this element in low-temperature sphalerite is most often between .01–.1 per cent. The .015–.030 per cent gallium reported from low-temperature Montevecchio, Sardinia, sphalerite [31] is of this order of magnitude. Mesothermal sphalerite generally contains less than .01 per cent gallium and in the sphalerite analyzed from hypothermal and pyrometasomatic deposits, Table I, gallium was generally not detected. The analyses as summarized in Fig. 4 show that the gallium concentration increases in sphalerite from

25 Moritz, H.: *op. cit.*, 1933.
26 Rimatori, C.: Rend. Accad. Lincei, Cl. Sci. Fis. Mat. Nat., ser. 5, 13: 285, 1904.
27 De Launay, L. and Urbain, G.: *op. cit.*, 1910.
28 Vernadsky, W.: *op. cit.*, 1911.
29 Schneiderhöhn and Ramdohr: Lehrbuch der Erzmikroskopie, 2: 106–111, 1931.
30 De Launay, L. and Urbain, G.: *op. cit.*, 1910.
31 Cambi, S. C. L. and Malatesta, L.: *op. cit.*, 1936.

occurrences of decreasing temperature type. Graton and Harcourt have arrived at a similar conclusion [32] and have shown that this is supported by other published analyses of gallium in sphalerite.[33]

The distribution of germanium concentration in sphalerite from deposits of different temperature types is shown in Fig. 5. The data corroborate the conclusions of earlier writers [34] that the germanium concentration increases with decreasing temperature.

Fig. 6 shows the distribution of the cadmium concentration in the analyzed specimens. Cadmium was found in all sphalerites examined. Since 85 per cent of all the specimens contained .1–1 per cent cadmium and because the analyses report only the order of magnitude, many of the smaller, yet significant, quantitative variations in the concentration of cadmium were not detected. The data do show that the sphalerite from low temperature deposits in most cases contains .1–1 per cent cadmium and that the cadmium concentration in sphalerite from deposits of higher temperature types is not as often of this magnitude. There are analyses reporting a concentration of 1 per cent or greater in both high and intermediate type sphalerite and in some of the high temperature occurrences less than .1 per cent cadmium is present in the sphalerite.

Previously published quantitative analyses of sphalerite that include cadmium determinations all show a cadmium concentration of .01 per cent or greater as far as the author is aware. On the basis of analyses from low temperature deposits in the Tri-State district in the Mississippi Valley,[35] Northern Arkansas,[36] Western Kentucky,[37] and Silesia,[38] it may be stated that there is

[32] Graton, L. C. and Harcourt, G. A.: *op. cit.*, pp. 814–815, 1935.

[33] Papish, J. and Stilson, C. B.: Am. Min., 15: 523–525, 1930.

[34] Goldschmidt, V. M. and Peters, Cl.: *op. cit.*, p. 153, 1933. Graton, L. C. and Harcourt, G. A.: *op. cit.*, pp. 815–816, 1935.

[35] Lindgren, W.: *op. cit.*, p. 435, 1933. Schmidt, A. and Leonhard, A.: Rept. Geol. Surv. of Mo., p. 392, 1874. U. S. Geol. Surv., Mineral Resources, Pt. 1, p. 249, 1927. Waring, W. G.: Trans. A. I. M. E., 57: 657–670, 1917.

[36] McKnight, E. T.: U. S. Geol. Surv. Bull. 853, p. 108, 1935.

[37] Ries, H.: Economic Geology, 6th Ed., p. 798, New York, 1930.

[38] Juretza, F.: Metall und Erz, 12: 235, 1915. Budgeon, N. F.: Cadmium: its Metallurgy, Properties, and Uses, p. 2, London, 1924. Meigen, W. and Schnarschmidt, O.: Zeit anal. Chem., 64: 215, 1924.

rarely over .6 per cent cadmium in sphalerite from low temperature deposits of other than epithermal type. A greater variation in cadmium concentration is indicated for sphalerite from intermediate and high temperature deposits. As little as .1 per cent cadmium is found in almost pure sphalerite from two deposits in the Slocan District, B. C.,[39] but as much as 1.61 per cent cadmium is reported[40] in sphalerite from the mesothermal deposit at Tsumeb, S. W. Africa. Sphalerite from Franklin, N. J. contains .09 per cent cadmium,[41] and in sphalerite from Bottino, Tuscany, there is 1.23 per cent cadmium.[42]

The data available suggest that cadmium is present in all sphalerite in amounts of .01 per cent to several tenths of a per cent, that low temperature sphalerite from other than epithermal veins rarely contains over .6 per cent cadmium, and that the cadmium concentration in sphalerite from intermediate and high temperature vein deposits varies from .01 to over 1 per cent. High concentrations of cadmium would seem most likely to occur in sphalerite from deposits of other than low temperature type.

Relation of Minor Element Concentration to Metallogenetic Groups of Deposits.

A closer similarity in composition of sphalerite from a single metallogenetic group of deposits than from deposits of a single temperature group suggests a further correlation between the minor element content and the geology of sphalerite occurrence. The low temperature deposits offer the best opportunity for such a study since deposits from several provinces are represented by sphalerite analyses. These are the lead-zinc deposits of the Mississippi Valley Province, the European zinc ores of Mississippi Valley type, and the Central Kentucky barite veins. Spectroscopic analyses of sphalerite from these districts are collected together in Table III. There are fewer analyses of sphalerite from districts in which the ores are of intermediate or high temperature

[39] Rept. Comm. on Zinc Resources of B. C., Mines Branch, Ottawa, pp. 14, 15 and 66, 1906.

[40] Meigen, W. and Schnarschmidt, O.: *op. cit.*, p. 216, 1924.

[41] Palache, C.: U. S. Geol. Surv. Prof. Paper 180, p. 27.

[42] Doelter, C.: *op. cit.*, p. 309, Analysis No. 32.

TABLE III.

ANALYSES OF SPHALERITE FROM LOW TEMPERATURE DEPOSITS IN SELECTED REGIONS.

No.	Locality	Cd	Mn	Ge	Ga	In	Sn	Tl	Co	Ni	Bi	Mo	As
	Mississippi Valley Province.												
1	Joplin, Mo.	—	–	—	–								
2	Carterville, Mo., "Ruby Blende" on No. 6.	—		—	–								
3	Jasper Co., Mo., "Ruby Blende" on No. 7.	—		—	–								
4	Granby, Mo., Deposited 110°–115°	—		–	—								
5	Empire, Kansas	—	–	–	—				+	+			
6	Carterville, Mo., Alexandra Mine	—	–	–	–				+	+			
7	Jasper County, Mo., Hastings Mine	—	–	–	–				+	+			
8	Chitwood, Mo., King Jack Mine	—		–	—				+	+			
9	Carterville, Mo., Alexandra Mine	—		–	—				+	+			
10	Hazel Green, Wis., Badger Mine	—	–	–	–								
11	Southeastern Mo., Deposited 105°–125°	—		—	—	–			+				
12	Rush, Arkansas, Morning Star Mine	—		–	—				+	+			
13	Gt. Slave Lake N. W. T., Lead Zinc Claims	—	–	–									
	European Zinc Ores of Mississippi Valley Type.												
14	Upper Silesia, Bleischarly Mine	—	–	–				—					+
15	Stolberg-Aachen, Diepenlinchen Mine	—	–	–				—					
16	Welkenraedt, Moresnet region	—	–	—				—					+
17	Iserlohn, Westphalia	—	–	—				—					
	Central Kentucky Barite Veins.												
23	Danville, Ky., Boone Creek Vein	—		–	—	–							
24	Hayden Vein, Boyle Co., Deposited at 70°–90°	—		–	—								
25	Henry Co., Ky., Lockport Vein	—		–	—								
26	Franklin Co., Ky., Clark Vein	—		—	—	–							
27	Duval Station, Ky., Wm. Davis Vein	—		—	—	–							

type and there is an increase in variation of other geologic conditions in these cases. Similarities in composition would be based on less data and differences might be due to a greater influence of other factors affecting compositional differences in sphalerite.

Analyses numbers 1–12 (Table III) are of sphalerite from four districts in the Mississippi Valley province. Cadmium, ger-

manium and gallium were detected in all cases. Cobalt, nickel, and up to .01 per cent manganese are present in some but not all of the sphalerite. Indium was detected in one analysis.

Previously published analyses of sphalerite and ores from the Mississippi Valley province, chiefly from the tri-state zinc district,[43] indicate that gallium is present in larger amounts than in sphalerite from most other types of deposits. Germanium has been frequently reported, whereas indium and tin, reported by some investigators, have not been found by others. Palladium, arsenic, cobalt, bismuth, and manganese have each been reported once. Traces of cobalt and nickel were found in the concentrates and a small amount of thallium has been detected in the flue dust resulting from the calcination of the blende concentrates. Analyses of pure material and concentrate suggest that sphalerite from the tri-state district and the zinc deposits of Northern Arkansas contain .1–.6 per cent cadmium. It may be concluded from analyses in Table III and previously published information that the sphalerite from the Mississippi Valley province contains a restricted group of minor elements in distinctive quantity as summarized in Table IV.

The zinc deposits in the sedimentary rocks of Belgium, Rhenish Prussia, Westphalia, and Upper Silesia are a related group of deposits that have often been compared with those in the Mississippi Valley province. Minor elements have been reported chiefly from the Upper Silesian deposits.[44] Analyses have shown

[43] Graton, L. C. and Harcourt, G. A.: *op. cit.*, 1935; Papish, J. and Stilson, C. B.: Am. Min., *op. cit.*, 1930; Hillebrand, W. F. and Scherer, J. A.: Jour. Ind. Chem., 8: p. 225, 1916; Hassler, E. L.: Proc. Oklah. Acad. Sci., 14: 67–68, 1934; Urbain, G.: *op. cit.*, 1909; Claussen, G. E.: *op. cit.*, 1934; Waring, W. G.: *op. cit.*, 1917; Lindgren, W.: *op. cit.*, p. 435, 1933; Schmidt, A. and Leonhard, A.: *op. cit.*, p. 392, 1874; U. S. Geol. Surv. Min. Resources, Pt. 1, p. 249, 1927; McKnight, E. T.: *op. cit.*, 1935.

[44] Cadmium, germanium, manganese, indium, bismuth: Graton, L. C. and Harcourt, G. A.: *op. cit.*, p. 803.

Cadmium: Juretzka, F.: *op. cit.*, 1915; Budgeon, N. F.: *op. cit.*, 1924; Meigen, W. and Schnarschmidt, O.: *op. cit.*, 1924.

Germanium: Urbain, G.: *op. cit.*, 1909; Goldschmidt, V. M. and Peters, Cl.: *op. cit.*, 1933.

Thallium: Von Kobell, F.: *op. cit.*, 1871. (*continued on page 516*)

TABLE IV.

SUMMARY OF MINOR ELEMENT CONTENT OF SPHALERITE FROM SELECTED REGIONS.

	Lead and Zinc Deposits Miss. Province.	European Zinc Ores of Miss. Type.	Barite Veins Central Kentucky.
Always present:	Cadmium .1–.6% Germanium Gallium	Cadmium .1–.3% Germanium Thallium .01–1%	Cadmium .1–1% Germanium Gallium .01–.1%
Often present:	Manganese <.01% Cobalt Nickel	Manganese <.01% Arsenic	Indium
Less commonly present in spectroscopic quantities:	Indium Tin Arsenic Palladium Bismuth	Indium Gallium	

thallium, tenths to thousandths of a per cent arsenic, as much as .1 per cent germanium, and .1–.3 per cent cadmium. Gallium has been reported in very small amounts but has often not been detected. Indium has been reported in traces in the sphalerite and in amounts of hundredths of a per cent in flue dusts and slimes. Bismuth, antimony, and manganese have each been reported by a single investigator.

Similar minor elements were found by the writer as indicated in analyses 14–17 (Table III). Cadmium, germanium, manganese and thallium were present in all and arsenic was found in two of the four analyses. The minor elements present are summarized in Table IV. This indicates that the European zinc ores of Mississippi Valley type are also an example of deposits of a single metallogenetic group that contain a distinctive group of minor elements in sphalerite.

Analyses numbers 23–27 of sphalerite from the low temperature barite veins of Central Kentucky are representative of a genetically related group of mineral deposits of small areal extent.

Gallium: Papish, J. and Stilson, C. B.: *op. cit.*, 1930; de Boisbaudran, L.: Compte Rendu, 82: 1098, 1876.

Indium: Brandes, W. and Geller, A.: Zeit, prakt. Geol., 41: 160, 1933; Feiser: Neues Jahrb. Ref., 1: 152, 1933.

Antimony and Arsenic: Stappenbeck, R.: *op. cit.*, p. 86, 1928.

Arsenic: Schneiderhohn, H.: *op. cit.*, p. 391, 1930.

The sphalerite, which occurs in small quantities in these veins, is characterized by up to .01 per cent germanium, .01–.1 per cent gallium, cadmium, and in some cases small amounts of indium.

Other examples of distinctive minor elements in sphalerite from genetically related deposits have been described. De Launay and Urbain [45] have shown that mercury is characteristically present in sphalerite from deposits in the Mediterranean region and that both mercury and antimony are commonly present in the sphalerite from the Tertiary zinc deposits of North Africa. Tornquist [46] has found arsenic in sphalerite from lead-zinc veins in the Eastern Alps, which are of late Cretaceous and Pliocene age.

The presence of a distinctive minor element content in sphalerite from a single province is further emphasized by contrasting the composition of the sphalerite from the different groups of deposits discussed above. The list of minor elements in sphalerite from three groups of low temperature deposits in Table IV is a summary of all data. Contrast of the analyses from the European zinc deposits with those of Mississippi Valley sphalerite shows that thallium occurs in greater amount, manganese is more commonly present and arsenic is present in analyses from European deposits. Gallium, cobalt and nickel are not generally detected in analyses representative of European zinc deposits yet are commonly present in Mississippi Valley sphalerite. Similarities include the germanium content, the infrequent report of tin, indium and bismuth, and the absence of molybdenum in the analyses from both provinces. In sphalerite from the Central Kentucky barite veins, the gallium content is consistently .01–.1 per cent which is higher than that in any of the European analyses and most of the Mississippi Valley sphalerite analyses. The Central Kentucky sphalerite differs also in that manganese, cobalt and nickel have not been detected. The germanium content is comparable in sphalerite from all three provinces.

The analysis of sphalerite from the zinc prospects at Great Slave Lake, number 13, is of interest because these deposits show similarities to both American and European deposits of Mis-

[45] De Launay, L. and Urbain, G.: *op. cit.*, 1910.

[46] Tornquist, A.: *op. cit.*, 1930.

sissippi Valley type. The minor constituents of the sphalerite are also intermediate between those of the two provinces. The minor element content resembles that of the European deposits in that gallium, cobalt and nickel were not detected, but the absence of arsenic and thallium is typical of Mississippi Valley sphalerite analyses.

SUMMARY AND CONCLUSIONS.

Available data suggest that compositional variation in sphalerite is related to the geological occurrence of the mineral. The variations in the kind of minor constituents in sphalerite and the order of magnitude of each have been correlated with two geological factors, namely temperature type of the sphalerite deposit and the metallogenetic province represented.

Evidence for a correlation between temperature type of deposit and minor element content is derived from a study of the distribution of minor element concentration in analyses from low, intermediate, and high temperature deposits. Arsenic, thallium, antimony, and mercury are found almost exclusively in low temperature sphalerite and molybdenum in sphalerite from mesothermal deposits. Germanium, gallium, and manganese show a clear relationship to the temperature type of deposit. The concentration of manganese increases in successively higher temperature deposits whereas the germanium and gallium concentrations decrease. The concentration of indium is least in low temperature deposits, but is most generally greatest in deposits of intermediate temperature type. Although not as clearly shown by the data presented, the greatest concentrations of tin and cadmium appear to be most common in sphalerite from deposits of other than low temperature type.

Sphalerite from the same metallogenetic group of deposits contains similar kinds and amounts of minor constituents but the composition of the sphalerite from each region is distinctive. The composition of sphalerite from the Mississippi Valley deposits, most of which contains cobalt and nickel, is different from that of the low temperature European zinc deposits of Mississippi

Valley type, which is distinguished by the presence of thallium and the lack of gallium, cobalt, and nickel. These minor constituents also contrast with those in sphalerite from the barite veins of Central Kentucky.

Lack of similarity of the composition of sphalerite from different metallogenetic regions is indicated by the analyses from the barite veins of Central Kentucky, lead-zinc deposits of the Mississippi Valley and the European zinc deposits of Mississippi Valley type, yet it is commonly believed that all were formed at low temperatures. Such contrasts in minor element content in sphalerite from deposits of similar temperature type may be ascribed not only to the variable temperature of sphalerite formation within the range considered, but also, and in large part, to the contrasting chemical character of the depositing solutions in the different metallogenetic regions. Similarly, the character of the solutions in a metallogenetic province are presumably responsible for the similarity of composition of the sphalerite within a single province. This in turn suggests that the difference in type of magmatic source of vein forming solutions might be reflected in the minor element content of the sphalerite. Sphalerite that has clear affiliations with different stages of magmatic differentiation or with particular kinds of igneous rocks must be investigated to determine the possibilities of such a correlation.

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AIKINITE AND SILVER ENRICHMENT AT THE ST. LOUIS MINE, BUTTE COUNTY, IDAHO.

ALFRED L. ANDERSON.

ABSTRACT.

The rare bismuth mineral, aikinite ($Cu_2S.2PbS.Bi_2S_3$), was found in such abundance at the St. Louis mine in Butte County, Idaho, that, because of a high silver content, it was hand-sorted and shipped to smelters. It is here shown that the high silver content was the result of selective replacement of the aikinite by supergene argentite and native silver.

The deposit belongs to the group of epithermal deposits of mid-Tertiary age and is enclosed in Tertiary andesite and tuff. The geologic setting and a fairly detailed description of the occurrence are given.

INTRODUCTION.

THE St. Louis mine in Butte County, Idaho, is unique in that it contains notable amounts of the otherwise rare mineral aikinite ($Cu_2S.2PbS.Bi_2S_3$), a mineral which, so far as the writer knows, has been recorded only at Berezovsk, Ural Mountains, and at the Sells mine, Alta, Utah.[1] In fact the bismuth was so abundant that it had been mined and shipped to smelters in the Salt Lake region, not because of the bismuth but because of an extraordinarily high silver content. Much of the ore that was shipped contained several hundred ounces of silver to the ton. Consequently, the "bismuth ore" was much sought after, carefully sorted and sacked, and shipped as an ore of silver.

The mine was examined along with others during geologic studies in the Lava Creek district in 1928 and the property was described in some detail in the ensuing report on the district.[2] In this report the writer by etch tests and chemical analyses tentatively identified the mineral of the "bismuth ore" as aikinite,

[1] Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 825, Rev. of part 3, Determinitive Table, p. 23, 1934.

[2] Anderson, A. L.: Geology and ore deposits of the Lava Creek district, Idaho. Idaho Bur. Mines and Geol. Pam. 32, 1929.

but because of the pressure for an immediate report on the district, he did not have the opportunity to work out the association of the bismuth and silver and had to conclude that the bismuth mineral probably was a silver-rich variety of aikinite. Since there is also a silver-lead-copper-bismuth sulphide, benjaminite, the writer was not satisfied with his tentative identification as aikinite and later resumed study of the ore, particularly after it was called to his attention that the final shipment of "bismuth ore," which had contained as much bismuth as earlier shipments, failed to give appreciable returns in silver. The sudden disappearance of the silver immediately raised the question of what had become of it. To find an answer to this question and to learn just what the associations of the silver and the bismuth mineral actually were, the writer carried the study further. This paper, therefore, presents the results of the belated investigation, and also gives a more comprehensive description of the locally abundant but otherwise rare mineral aikinite than was possible in the earlier report.

Location.—The St. Louis mine is on a tributary of Champagne Creek in the old Era district, now included in the enlarged Lava Creek district, in Butte County, about 20 miles from Arco, the rail point from which ore shipments were made to the smelters. The property lies at an altitude of about 6,300 feet in the treeless mountains about 4 miles north of the margin of the Snake River Plain in sec. 15, T.3N., R24E, Boise meridian. It is about 4 miles from the main highway which passes through Arco and the Craters of the Moon National Monument.

History and Development.—The Lava Creek district, one of the important silver producers in Idaho from 1884 to 1886, has had a phenomenally short life. The district's rise was rapid owing to many discoveries of rich silver-bearing veins at about the same time, and its decline was equally rapid because the oxidized and enriched ores were soon exhausted and the primary base-metal sulphides, to which the rich silver ores gave way at slight depth, were not amenable to amalgamation, then the common metallurgical practice. After the collapse of the early mining activity, the district as a whole was relatively inactive, until several years after the World War, when attention was directed to the possi-

bility of utilizing the base-metal sulphides as ores of lead and zinc. The St. Louis mine was one of the old mines that was revived, and it subsequently made several shipments of ore until the late summer of 1928. Failure of a car of the "bismuth ore" to net any returns in silver at that time caused the mine to suspend operations and the property has since been inactive.

The mine was developed by three principal tunnels, two from the east and one from the south, and by an inclined shaft 160 feet deep. The tunnels consisted of more than 1,500 feet of workings. All tunnels were inaccessible, except the main No. 3 tunnel which was about 800 feet long and which passed less than 50 feet below the highest part of the outcrop. Much of the work in 1928 was confined to the shaft and to short drifts therefrom. All ore above the No. 3 had been stoped.

Local estimates have placed the production as high as $75,000, including the ores shipped in 1928. Actual production may have been a fifth as much.

GEOLOGIC SKETCH.

Although some complexly folded and faulted sandstones, shales, and limestones of Mississippian (Brazer) age occur in the district, most of the deposits are associated with Tertiary volcanic rocks and are contained in lavas and tuffs (Challis volcanics) of upper Oligocene (?) age, which have been arched into a broad anticline with Miocene granite and porphyry dikes intruded near and along the core of the anticline. Near the intrusives, the volcanics have been extensively shattered, possibly by the force of intrusion, and have otherwise been broken into a mosaic of blocks by normal faults, produced not so much from collapse of the roof of the arch as from the upward pressure that might have been exerted by a rising magma.

Fracturing of the volcanic rocks also provided fissures for the circulation of mineral-bearing fluids. Near the axis of the broken anticline, the mineralized fractures trend nearly east and west, but in the Champagne Creek area, which is several miles therefrom, the mineralized fissures have a northward trend.

Most of the faults in the Champagne Creek area are difficult to recognize on the surface because of poor rock exposures, a result of intense and widespread hydrothermal alteration that has softened and made the rocks particularly susceptible to weathering and reduction to smooth slopes. Most of the fissures dip steeply west. The special locus of mineralization in which the St. Louis mine is located suggests the presence of an underlying intrusive that shattered the rocks during its intrusion and is not yet exposed by erosion.

The deposits are unlike most of the ore deposits in other parts of the state in that they occur in Tertiary lavas and tuffs and belong to the group of epithermal base-metal deposits. For the most part they occur along fissures and brecciated zones in the volcanics, and are associated with intense and widespread wall-rock alteration. Filling of open spaces has generally been an important process of deposition, but replacement of the highly altered wall and included wall fragments also has played a prominent role in their formation. The district is notable for its great number of minerals and for its many kinds of deposits.

GEOLOGIC RELATIONS AT THE ST. LOUIS MINE.

Although irregularly mineralized, the St. Louis vein is remarkably persistent and may be traced probably for half a mile on the surface. It forms an inconspicuous outcrop, but is somewhat more resistant to erosion than the wall rock, which was less intensely silicified. The vein has a general trend of N. 5° E.; it dips from 40° to 60° west. South of the shaft the hanging wall is intensely altered andesite with sericite, quartz, and pyrite extensively developed, but the foot wall is a white, thin-bedded, water-laid tuff showing the same type of hydrothermal alteration. North of the shaft the vein is wholly within the tuff.

The ore occurs in small irregular lenses and bunches from 6 to 15 inches thick, and in small stringers cementing the brecciated rock along the fissure. Considerable ore also is disseminated in the wall where it replaces the altered andesite and tuff. In fact most of the ore is actually a replacement of the country rock and

is either in the form of compact massive bands and nests set off sharply from the replaced rock or in the form of closely spaced to widely scattered granules and crystals disseminated through the altered rock.

MINERALOGY.

The primary ore is made up almost entirely of argentiferous galena, sphalerite, wurtzite, pyrite, marcasite, and aikinite in a quartz-dolomite gangue. It also has minor tetrahedrite, chalcopyrite, and calcite. The presence of wurtzite and marcasite in the ore along with the sphalerite and pyrite is perhaps as unusual as the presence of the locally abundant aikinite.

These minerals were not all deposited at the same time but in two successive stages separated by a structural break of appreciable magnitude. Most of the base-metal sulphides were deposited early, the aikinite, the carbonates, and two of the lesser sulphides, later. Because of the structural separation and the kinds of minerals deposited before, and after, the early stage of deposition may be conveniently referred to as the base-metal stage, and the later, as the aikinite stage.

Although the silver was the most important metal of the deposit, it was found to belong to neither of the two stages, except in relatively subordinate amounts, and as described later it represents a secondary enrichment.

Minerals of the Base-Metal Stage.

The minerals of this stage are associated with and tend to replace chalcedonic quartz that has entered into and has produced more or less pronounced silicification of the otherwise sericitized andesite and tuff. The sulphides tend to form compact seams and masses in and bordering original fractures and also to form disseminated crystals and granules in the altered rock for several feet on either side. The galena, sphalerite, and pyrite are in general considerably more abundant than the wurtzite and marcasite.

Pyrite and Marcasite.—Much of the pyrite has a cubic form and occurs as crystals in the altered wall rock and as crystals and

residual grains in the other sulphides. Some of the pyrite is notably corroded by chalcopyrite and shows a typical exploded-bomb structure. In places it also has been extensively fractured and the fragments have been cemented and partly replaced by sphalerite, chalcopyrite, and tetrahedrite. Some pyrite also appears less abundantly as reniform and globular masses, commonly with radiating structure, and is essentially indistinguishable, except microscopically, from similar globular and reniform grains and masses of marcasite. The two are invariably intimately associated and appear to be intergrown.

Sphalerite and Wurtzite.—The zinc sulphides, like the iron sulphides, are intimately associated in the same masses and cannot be readily distinguished, except microscopically. However, the sphalerite may occur without the wurtzite. Where they occur together, they may be in the massive ore itself, or in grains disseminated in the wall rock. The grains are pale brown to dark brown in color and locally form semi-spherical masses. Some of the grains have a suggested hexagonal outline, but the wurtzite tends more commonly to occur as concentric shells and to possess with associated sphalerite a pronounced radiating, almost fibrous structure. These peculiar spherical wurtzite masses have been described in some detail by Umpleby.[3] He has pointed out that in cross section the masses appear to be made of an outer band of dark brown dense wurtzite separated from a large central light brown area by a dense black layer, also of wurtzite. As pointed out by Umpleby, the inner light brown part is rather spongy in texture and has a distinct radial structure, the interstices being filled by calcite. He also mentions that the wurtzite is intimately associated with sphalerite, as well as with galena and pyrite; and that in places it is entirely surrounded by these minerals, or appears as distinct grains intergrown with them. He states that the mineral is also found locally as spherical masses traversed by veinlets of galena and elsewhere as parts of apparently continuous veins, other parts of which are sphalerite. He

[3] Umpleby, J. B.: Geology and ore deposits of the Mackay region, Idaho. U. S. Geol. Surv. Prof. Pap. 97: 86–88, 1917.

further points out that this relationship occurs not only in the vein material proper, but also within patches of ore minerals that unquestionably replace the wall rock, locally more than an inch from any veinlet. He favors the view that the two zinc sulphides are essentially contemporaneous and, therefore, both primary.

The writer has observed that some of the sphalerite which occurs in the aikinite ore has been considerably brecciated and is in places cemented by tetrahedrite and chalcopyrite. Some of the sphalerite also shows an exploded-bomb structure where it is replaced by tetrahedrite.

Galena.—The galena forms cubic grains in the wall, but it is generally without crystal borders, where it occurs in seams and lenses with the other sulphides. However, in the central zone of some of the seams, where sphalerite and pyrite lie at the borders, it may occur in distinct cubes and cubo-octahedrons. It generally penetrates the zinc and iron sulphides to some extent and it also contains remnants of them as residua of replacement. The galena is argentiferous and has, commonly, one ounce of silver to each per cent of lead in the ore, which is hardly enough to explain the high silver content of some of the ore.

Tetrahedrite and Chalcopyrite.—The tetrahedrite and chalcopyrite reappear in the aikinite stage where they are much more abundant than they are in the base-metal stage. In the latter stage they occur as microscopic grains in the galena and as microscopic veinlets in the zinc and iron sulphides. In places the veinlets apparently replace the sphalerite and iron sulphides. Some of the tetrahedrite has been penetrated and partly replaced by the chalcopyrite. Consequently, the age relations between the two minerals are definite. Seams of each are cut off sharply at galena contacts.

Paragenesis.—Except for the presence of the marcasite and wurtzite, the minerals and their sequential relations are entirely normal. Because the marcasite and pyrite and the wurtzite and sphalerite are in each case so intimately intergrown, they must be essentially contemporaneous. The mineral sequence is quartz, pyrite and marcasite, sphelerite and wurtzite, tetrahedrite, chalcopyrite, and galena.

The significance of the sphalerite-wurtzite association has been discussed by Umpleby,[4] but he has not been able to find a satisfactory explanation for the intimate association of the two forms of zinc sulphide, the one, sphalerite, a mineral believed to be precipitated from alkaline solutions, and the other, wurtzite, from acid solutions. The writer is not yet ready to discuss the problem.

Minerals of the Aikinite Stage.

The minerals of the aikinite stage include dolomite and aikinite as the abundant minerals and tetrahedrite, chalcopyrite, and calcite as those of lesser abundance. This assemblage was not recognized by Umpleby. The minerals in it were superposed upon the earlier filling, and form nests and seams cutting the base-metals and country rock. They also occur as fillings, or partial fillings, in vugs or open ore breccias. Much of the younger ore is in more or less massive bands and bunches in the vein, but some is scattered in and through the earlier sulphides.

Carbonates.—Dolomite with variable amounts of calcite is present in all the ore that contains the aikinite and is more or less contemporaneous with it. In the compact ore the sulphides of the assemblage are distributed through the carbonate, which they appear to replace; but in ore that partly filled open spaces, the intimately associated dolomite and sulphides are separated from the wall by a narrow band of pure dolomite and from the opening by a crust of dolomite and calcite crystals. In the open clefts the dolomite builds good rhombohedral crystals. Obviously, the carbonate deposition initiated the younger stage of deposition and outlasted the associated sulphides.

Tetrahedrite.—Tetrahedrite is invariably found in the aikinite bands, and the association is so persistent that such tetrahedrite can belong only to the aikinite stage of deposition. Wherever the tetrahedrite occurs, it is penetrated and replaced by aikinite crystals, which in many places are so extensive, that the tetrahedrite appears as only minute inclusions. Some of the young tetrahedrite has penetrated into and replaced the earlier minerals, but

[4] Op. cit., pp. 86–89.

in that event it is also accompanied by the bismuth mineral. The tetrahedrite is not recognizable, except microscopically, because it is less abundant than and overshadowed by the aikinite.

Aikinite.—The aikinite is rather generously distributed through the vein in the form of scattered microscopic crystals and in larger compact, apparently massive seams and lenses several inches wide. At least one large lens of nearly pure aikinite weighing several hundred pounds was mined, and the writer was given a specimen measuring more than a foot across.

The aikinite may be recognized easily in the hand specimen. It has a blackish, lead-gray color and streak and generally occurs in tabular, or acicular crystals which, if not too compactly spaced, are identified readily in the hand specimen. Even the apparently massive, homogeneous ore is actually made up of closely spaced individual crystals (Fig. 1). Some of the crystals appear as short narrow columns, tapering toward one end like a needle; others, toward both ends. Some of the longer, needle-like crystals are curved at the ends (Fig. 2). Cross sections appear nearly square (Fig. 1).

As pointed out earlier the aikinite needles protrude into and replace grains of tetrahedrite and commonly retain minute tetrahedrite inclusions as residua of replacement. The laths and needles also penetrate and replace the older minerals, always assuming their own idiomorphic form. The zinc sulphides seem to have been penetrated more by it than by the other minerals. However, most of the aikinite is not in the other sulphides but is in scattered crystals with remnant tetrahedrite in the matrix of the carbonate gangue.

The writer's original determination of the bismuth mineral as aikinite, based on etch reactions and incomplete chemical analyses, proved on further study to be correct. Verification was based on etch tests, which corresponded to the etch test for aikinite described by Short,[5] and on strong microchemical tests for lead, copper, bismuth, and sulphur, but not on tests for silver. The mineral shows very pronounced anisotropism with reflected polarized

[5] Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 825: 76, 1931.

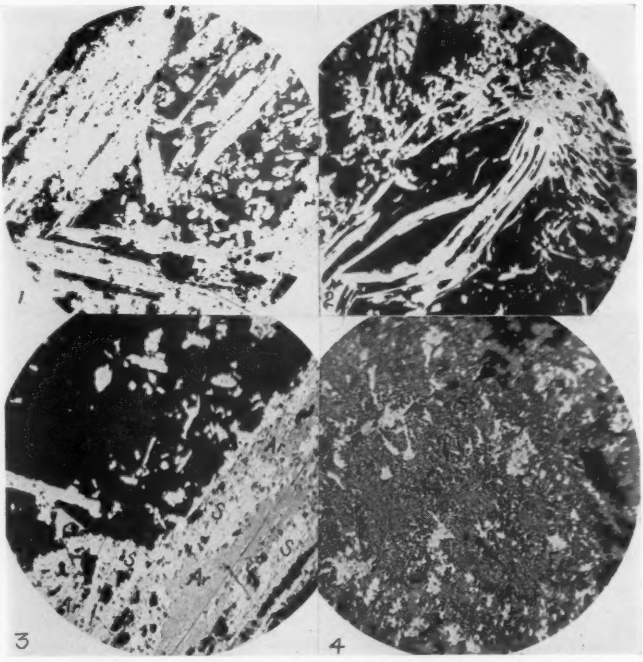

FIG. 1. "Bismuth ore" showing white aikinite laths and cross sections in grayish carbonate gangue. × 77.

FIG. 2. "Bismuth ore" showing the acicular nature of much of the aikinite (white) and the bending of the crystals in replacing dolomite (dark gray). The aikinite is partly replaced by spongy masses of native silver (S). × 87.

FIG. 3. "Bismuth ore" showing a large blade of aikinite wholly replaced by argentite (Ar) and by spongy native silver (S). The aikinite apparently was first replaced by argentite and the argentite by the silver. × 87.

FIG. 4. Intimate replacement of the aikinite (medium gray) by argentite (darker gray) and by native silver (white). × 140.

light and has distinctive polarization colors. It proved not to be a silver-rich aikinite, or benjaminite.

Chalcopyrite.—Most of the younger chalcopyrite appears as a thin film on and as a filling of fractures in the "bismuth ore." In places the thin seams cut and replace the aikinite as well as grains of earlier minerals. Its deposition was out-lasted by that of dolomite and calcite as none of it occurs on the faces of the dolomite crystals in the vugs.

Paragenesis.—From the distribution of the minerals and their replacement relationships, the mineral sequence of the aikinite stage is easy to interpret. Dolomite initiated the deposition and continued through and after the interval during which the tetrahedrite, aikinite, and chalcopyrite were deposited. The sequence of the sulphides was tetrahedrite, aikinite, and chalcopyrite. Calcite apparently was deposited with the dolomite during the closing stages of carbonate deposition.

Association of the Silver.

Study of the primary bismuth ore from the bottom of the 160-foot shaft and from ore at higher levels has revealed that aikinite is the only bismuth mineral present and that the aikinite has no abnormally high silver content as the earlier work seemed to indicate. Yet, the bismuth ore shipped to the smelters, except at the end, gave returns of several hundred ounces of silver to the ton of ore; and selected ore was reported to have contained more than 1,000 ounces of silver. Assays of some of the fairly pure aikinite collected by the writer gave more than 800 ounces of silver to the ton, while the ore selected for the quantitative analysis used to determine the composition and identity of the bismuth mineral contained 10 per cent silver. This ore appeared to be no different on casual inspection from the ore that later yielded only a little silver.

The high silver content of the ore could hardly be attributed to the associated minor tetrahedrite. However, study of the polished surfaces of the ore has given a clue to the high silver content. Neither aikinite nor the tetrahedrite is directly responsible.

The high silver content is due to the presence of argentite and native silver, both of which have replaced the aikinite and to lesser extent the tetrahedrite.

Aikinite and Silver Enrichment.—Study of polished surfaces of the ore from the higher levels of the mine shows that the aikinite crystals are not crystals of the pure mineral but are to greater or lesser extent argentite and native silver pseudomorphs of the aikinite. In places the silver minerals are wanting, or occur in small amounts along the margins of the aikinite crystals; but in other places the silver minerals have replaced the aikinite to such an extent that only the outline of the aikinite crystal remains.

The argentite has a smooth surface and is found only in the aikinite. The native silver occurs as sponge-like masses in and replacing the argentite, the tetrahedrite, and the aikinite (Figs. 2–4). In Fig. 2 the curved aikinite needles are only partly replaced at the ends by spongy masses of native silver. In Fig. 3 the aikinite crystal has been wholly replaced by argentite; and the argentite in part, replaced by native silver. Fig. 4 shows the argentite and native silver replacements in greater detail. In general the aikinite appears to have been more susceptible to replacement by the silver minerals than any of the other sulphides in the ore. The replacement was a selective one. Thus, the "bismuth ore" derives its high silver content from the intimate replacement of the aikinite by argentite and native silver and not from the presence of any silver that might have been a part of the aikinite itself, as in the mineral benjaminite.

Supergene Origin of the Silver.—The selective replacement of the aikinite and the spongy-like nature of the native silver is evidence enough that the enrichment is supergene, that the silver has been added from descending surface waters that probably had removed the silver from the original galena and tetrahedrite near or at the surface. That the enrichment is supergene is proven further by the fact that the aikinite shows decreasing amounts of the silver minerals with depth, so that at the bottom of the shaft there are none. The St. Louis mine is like the other mines in the

district, which were phenomenally rich at the surface because of supergene enrichment, but which became impoverished at shallow depth.

DISTRIBUTION OF THE ORE.

As pointed out earlier, the vein was not uniformly mineralized; but the ore occurred in it in scattered irregular lenses and bunches, in stringers, and in disseminations in the wall. The vein was followed south of the shaft for 165 feet; but only about 70 feet of it contained sulphides to any notable extent, the remainder had scattered grains of the base-metal sulphides. Seventy feet south of the shaft the vein contained about a foot of disseminated sulphides and from that point to the shaft, recurring lenses of galena up to 4 inches wide. A drift 35 feet below the No. 3 level and driven south of the shaft about 40 feet had opened up a considerable body of the bismuth ore, which was very rich in silver. The mine management reported that this ore body occurred as a bulge in the vein and formed a compact body 15 feet long on the strike, 12 feet on the dip, and 2½ feet in thickness. Although this ore had been mined, there remained in the face seams and stringers up to 8 inches thick in a crush zone several feet wide, which also contained some disseminated ore.

North of the shaft the ore ceased within a short distance and the fissuring was barely discernible; but 150 feet to the north the fissure again contained ore, mostly the base-metal variety. From there on the shoot was mined for more than 200 feet, the ore appearing in it as scattered lenses and seams a few inches wide. At that point a second vein, called the Dry Silver vein, was 15 feet to the east. This vein furnished several loads of rich ore at the surface. The unoxidized ore below contained mainly iron sulphide and aikinite.

The ore shoots were relatively small and uncertain, and pinched on both strike and dip. Some 60 feet below the No. 3 level the ore pinched to a mere stringer, but enlarged again at the bottom of the shaft where it contained considerable amounts of aikinite.

SUMMARY AND CONCLUSIONS.

Although the occurrence of the rare bismuth mineral, aikinite, in such amount that it could be hand-sorted and shipped as ore is worthy of note, its selective replacement by supergene argentite and native silver to change it to an ore of silver is perhaps of even greater interest. The answer to the question of what happened to the silver in the last car of the "bismuth ore" is not difficult to give. The final shipment was of ore mined deep in the shaft and below the zone of downward silver enrichment.

There is no need to point out the value of such microscopic studies as have been made in the present instance in dealing with the economic distribution of the valuable ore minerals. The silver-enriched bismuth ore resembled the unenriched ore so closely that there was no distinction between the two ores in the hand specimens; but the difference was indeed striking in the polished surfaces, inasmuch as the aikinite in the enriched ore was partly or completely replaced by pseudomorphous argentite and native silver.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge the material assistance received from Mr. Charles Alfred Rasor during the restudy of the ores. Mr. Rasor was then a graduate student at the University of Idaho and examined the polished surfaces as a part of his general course of study. By means of etch and microchemical tests he confirmed the writer's original identification of the bismuth mineral and also helped to establish the identity of the silver minerals. The photomicrographs used in this paper (except Fig. 1) are those made by Mr. Rasor.

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GROUND WATER IN THE OKLAHOMA PANHANDLE.[1]

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ABSTRACT.

An investigation begun in 1937 by the United States and the Oklahoma Geological Surveys, has shown that the depth to the water table in the Oklahoma Panhandle ranges from less than 25 feet in parts of major valleys to about 300 feet in parts of the uplands. In 8 upland areas the depth is between 50 and 100 feet. The thickness of the zone of saturation differs widely in these areas, the most promising of which totals about 80 square miles in northeastern Texas County. The pervious sands and gravels of the Ogallala formation, of Pliocene age, furnish most of the ground water, and one well yielding 960 gallons a minute from them has been used for irrigation since 1937. The formation ranges from less than 100 to more than 500 feet thick, the differences being due to relief on the pre-Ogallala topography and to post-Ogallala erosion. The alluvium is also an important source of water, as are the Dakota and Cheyenne sandstones, of Cretaceous age. A few wells yield water of variable quality from Jurassic and Triassic rocks, and many wells in the valleys of the eastern part of the area yield small supplies of highly mineralized water from Permian red beds.

INTRODUCTION.

THE fact that dependable supplies of good water can be obtained almost anywhere in the Oklahoma Panhandle by drilling a well of sufficient depth has made possible the settlement and continued occupancy of the area. Nearly all the water used is pumped from the ground.

In most localities the depth to the water table exceeds 100 feet and the cost of lifting large quantities of water has discouraged extensive development of ground water supplies for irrigation. However, the dry years of 1931–1939 aroused interest in irrigation from wells, and impetus was added in 1937 by the drilling of 2 deep wells for irrigation by the Panhandle Agricultural and Mechanical College at the town of Goodwell.

[1] Published by permission of the Director of the Geological Survey, United States Department of the Interior, and the Director of the Oklahoma Geological Survey.

[2] Introduced by O. E. Meinzer.

Late in the summer of 1937 the Geological Survey, United States Department of the Interior, in coöperation with the Oklahoma Geological Survey, began an inventory of the ground-water resources of the three counties in the Panhandle to anticipate any extensive ground-water development with a body of facts, and to outline areas where the water table is relatively near the surface.

At the close of field work in 1939 a detailed inventory of wells and springs had been completed in two of the three counties and

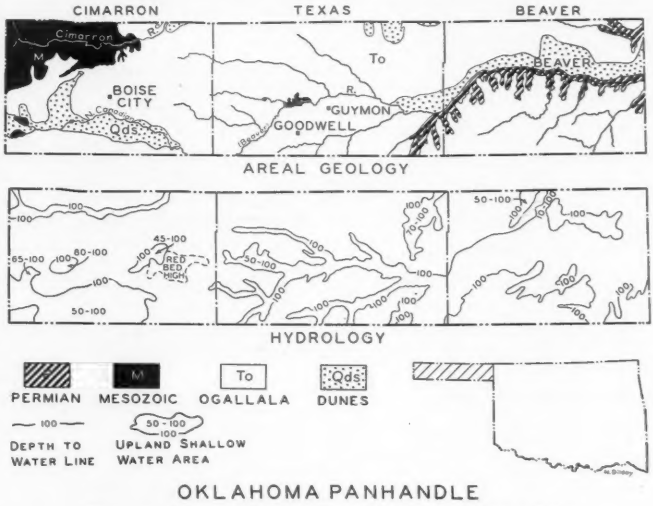

FIG. 1. Maps showing geology and hydrology of the Oklahoma Panhandle.

in about half of the third county. A report on the ground-water resources of Texas County was issued in 1939 as Bulletin 59 of the Oklahoma Geological Survey. The present paper offers a brief summary of the principal results for the Panhandle as a whole.

Location, Area and Topography.—The Panhandle is the narrow strip, 167 miles long and about 34½ miles wide, which is appended to the northwestern part of the main body of the State of Oklahoma (Fig. 1). It covers about 5700 square miles of the

Southern High Plains and is divided into 3 counties of similar size named, from east to west, Beaver, Texas, and Cimarron. The largest town is Guymon, with a population of about 2200 in 1930. The principal activity in the area is agriculture, and the chief cash crop is winter wheat. Cattle raising is important in the broken lands along the main valleys.

The Panhandle consists chiefly of flat upland plains which slope imperceptibly eastward from elevations of nearly 4900 feet down to about 2200 feet above sea level. The North Canadian (Beaver) and Cimarron Rivers and their large tributaries have carved their valleys 100 to 200 feet below the level of the adjacent uplands.

Because the Cimarron swings northward into Colorado and Kansas opposite Texas County, the 3 counties have different proportions of their areas in upland plains. About three-fourths of the area of Texas County and about two-thirds of Cimarron County are upland flat. The field study of Beaver County is incomplete, but it seems that upland flats do not constitute more than half its area.

In addition to the upland flats—true High Plains—there are considerable areas of flood plains in the larger valleys, and of broken lands—the breaks—between them and the uplands.

GROUND-WATER PROVINCES.

Almost all of the Oklahoma Panhandle is in the Great Plains Pliocene-Paleozoic ground-water province, in which late Tertiary and Quaternary sands and gravels are the principal aquifers, but water of poor quality is also obtained from underlying rocks of the Carboniferous system. The northwestern corner of the Panhandle, in Cimarron County, is in the Great Plains Pliocene-Cretaceous province, where, in addition to late Tertiary and Quaternary sands and gravels, the Dakota sandstone is an important aquifer.[3]

[3] Meinzer, O. E.: The occurrence of ground water in the United States. U. S. Geol. Surv. W. S. P. 489: 312 and Pl. 31, 1923.

GEOLOGY AND GROUND-WATER SUPPLIES.

The sedimentary rocks of the Oklahoma Panhandle range in age from Carboniferous to Quaternary, and there is a lava flow of late Tertiary age. The latter is not important as a reservoir for ground water.

Carboniferous.—The Carboniferous system is represented by generally red, sandy or silty shales and fine, red sandstones, of Permian age, which are best exposed in Beaver County. Locally there are thick, massive beds of gypsum. Many wells have been drilled into these rocks, but with few exceptions they have yielded only meagre supplies of water, which in many instances has proved too highly mineralized for domestic use, although it seems to be satisfactory for stock use. One well in this formation flows at the surface, and in another well, which formerly flowed, the water stands within a foot of the surface. The water from both these wells is highly mineralized, that from the second well never having been used for any purpose.

Triassic and Jurassic.—The Triassic and Jurassic systems are represented by red, variegated, and gray shales and sandstones that crop out chiefly along Cimarron River in northwestern Cimarron County [4] and occur as small inliers in central Texas County.[5] Only a few wells are known to obtain water from these rocks. The available evidence indicates that the mineral content of the water from them ranges within wide limits.

Cretaceous.—The Cretaceous system in the Oklahoma Panhandle consists of 3 formations, as follows: (1) the Purgatoire formation, of Lower Cretaceous age, consisting of the Cheyenne sandstone member below and the Kiowa shale member above; (2) the Dakota sandstone and (3) the Graneros formation, of Upper Cretaceous age.[6] These crop out principally in north-

[4] Stovall, J. Willis: The Morrison of Oklahoma and its dinosaurs. Jour. Geol., 46: 586–587, 1938.

[5] Schoff, S. L.: Geology and ground water resources of Texas County, Oklahoma. Oklahoma Geol. Surv., Bull. 59: 52–54, 1939.

[6] DeFord, R. K.: Areal geology of Cimarron County, Oklahoma. A. A. P. G., Bull. 11: 753–755, 1927. Stovall, J. Willis: Op. cit., pp. 586–588; and also, Advance notes on the geology of the Cimarron Valley of western Oklahoma. Proc. Okla. Acad. Sci., 17: 78–79, 1937.

western Cimarron County. The Cheyenne appears to be the aquifer in a few wells, two of which flow at the surface. The Dakota is reached by many wells, and many small springs issue from it. The water from these sandstones is generally of satisfactory quality, although hard.

Tests were made of the permeability of samples taken from outcrops of the Cheyenne and Dakota sandstones. The permeability coefficients of 6 samples of the Dakota ranged from 30 to 255 and averaged 105, and those of 3 samples of the Cheyenne ranged from 3 to 55.[7]

Tertiary.—The Tertiary system is represented chiefly by deposits of sand, gravel, silt, and clay, and mixtures thereof, tentatively referred to the Ogallala formation, of Pliocene age. The several lithologic types are arranged in many lenses and interpenetrating fingers. However, the gravels generally are in the lower part of the formation, and in many places lie directly on top of the older rocks. The formation becomes increasingly calcareous upward and includes near the top many feet of "mortar beds" or "caliche."

The Ogallala formation is the principal source of ground water in the Panhandle. More than half of all the existing wells draw water from it. The largest well in the area yields 960 gallons a minute from sands in the Ogallala, and is used for irrigation at the experimental farm of the Panhandle Agricultural and Mechanical College, Goodwell. Not only does the Ogallala yield water rather freely, but it also provides water which, although hard, is generally satisfactory for many uses.

The thickness of the formation differs widely from place to place because of relief on the unconformable surface below and erosion after deposition. From the logs of test wells drilled for gas and oil it is estimated that the original thickness of the Ogallala ranged from less than 100 feet to 500 or 600 feet (Fig. 2).

[7] The permeability coefficient is defined as the number of gallons of water a day at 60° F. that is conducted laterally through each mile of the water-bearing bed (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.

In the logs, the top of the red beds has been taken as the base of the Ogallala, but it is recognized that this interpretation may be in error if there are light-colored Cretaceous sediments between the Ogallala and the red beds. The recognition of such Cretaceous rocks in the logs is practically impossible because the record of materials above the red beds is usually very generalized.

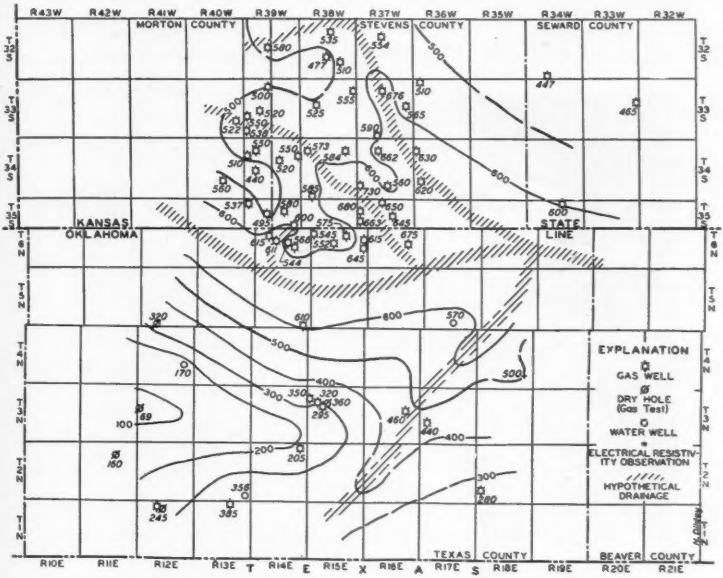

FIG. 2. Thickness in feet of the Ogallala formation in Texas County, Okla., and adjacent parts of Kansas prior to erosion. Based chiefly on logs of gas test wells (From Oklahoma Geological Survey Bull. 59.)

However, the thickness of the Cretaceous, if it is present under cover, may not be great. Fig. 3 shows the principal outcrops of Cretaceous rocks in parts of Colorado, New Mexico, Texas, Oklahoma, and Kansas, and a line suggesting the eastern limit of buried Cretaceous, along which erosion may have reduced the thickness of the Cretaceous before the Ogallala was deposited over it. The isopach map (Fig. 2) is crossed by this line. In central

Texas County, Oklahoma, Cretaceous rocks now recognized in inliers that formerly were mapped as entirely Triassic (?) have a total thickness of only about 15 feet[8]—less than the probable errors in the depths reported in the well logs.

As the Ogallala should have been thickest along pre-Tertiary valleys, the isopach map of Fig. 2 suggests an ancient drainage pattern.

The thickness of the zone of saturation in the Ogallala differs widely in response to differences in the thickness of the formation.

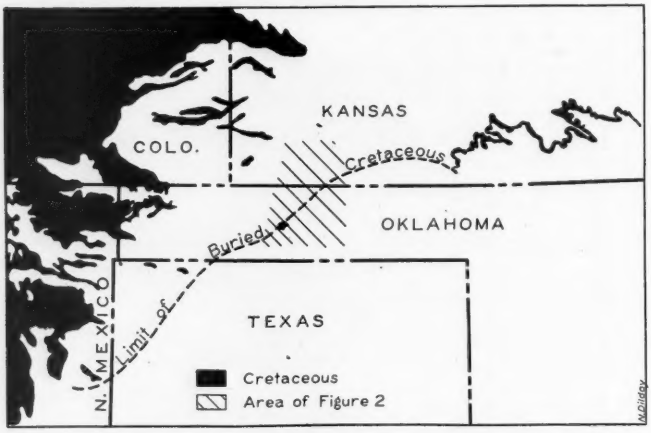

FIG. 3. Outcrops of Cretaceous rocks and possible eastward limit of buried Cretaceous.

It is also affected by differences in the shape and slope of the water table.

Quaternary.—The Quaternary system is represented by alluvium in the major valleys and by dune sand.

The alluvium is generally rather pervious and contains an important supply of ground water for stock and domestic use and for some irrigation. The discharge of the power-driven wells in the alluvium ranges from a few tens to several hundreds of gallons of water a minute. Some of the water from the alluvium

[8] Schoff, Op. cit., pp. 40, 54–57.

is as good as that from the Ogallala, but in localities where the Permian red beds crop out nearby, the water is highly mineralized.

The dune sands cover many square miles. They occur chiefly along North Canadian River, although there are also considerable areas of dunes far from the river in northeastern Texas County. The dune sands are relatively pervious, but because in general they are above the water table they do not furnish water directly to wells. However, a significant fraction of the rain falling on them may ultimately reach the ground-water reservoir.

THE WATER TABLE.

Figure 4 is a water table map for northeastern Texas County. The water table in the Ogallala formation slopes eastward or southeastward under the upland plains at an average rate of 15

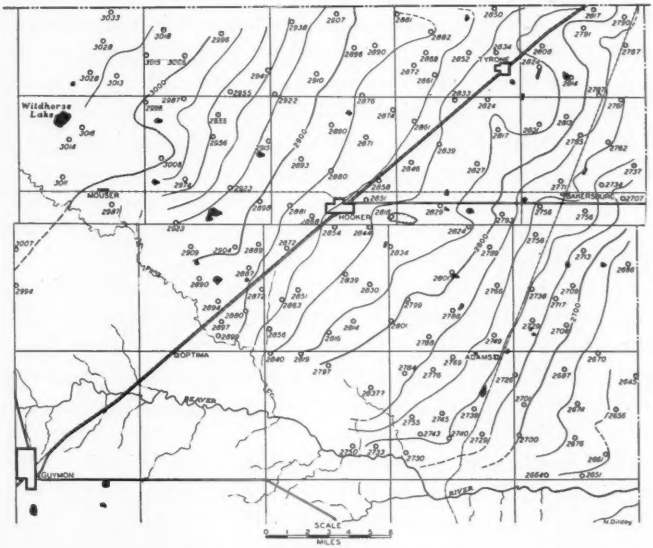

FIG. 4. Shape and slope of the water table in northeastern Texas County, Okla. Elevations on the water table are in feet above sea level. (From Oklahoma Geological Survey Bull. 59.)

or 20 feet to the mile, but there are irregularities due to unequal recharge in some areas and to discharge in others. A large nose in the northwestern part of the map and another near the town of Tyrone may be caused by recharge through broad, shallow depressions in parts of which lakes or ponds stand after heavy rains. Near North Canadian River, which is nearly or quite perennial along the stretch shown, the water-table contour lines swing upstream because ground water is discharging into the river.

AREAS OF MODERATELY SHALLOW GROUND WATER.

The depth to the water table as measured with a steel tape in wells ranges from a few feet to about 300 feet below the land surface.

Along the main valleys the depth to the water table in many places is less than 25 feet, and at most locations it is less than 50 feet. The areas of moderately shallow ground water along the North Canadian and Cimarron Rivers are rather narrow in Cimarron County but widen eastward to include large areas in Beaver County (Fig. 1). However, ground water is not to be had at shallow depths along all parts of the valleys. Along the lower 12 miles of the North Canadian Valley in Cimarron County the water table declines sharply eastward, and locally is more than 100 feet below the dry stream channel.

In most parts of the uplands the depth of the water table is more than 100 feet, and it is more than 200 feet in considerable areas in eastern Cimarron County, western and northern Texas County, and southern and northwestern Beaver County. There are, however, 8 upland areas where the water table is less than 100 feet below the surface (Fig. 1).

Possibly the most promising upland area for irrigation from wells is the one in northeastern Texas County, although even here pumping lifts are likely to be rather high. Measurements in 20 wells show that the water table is 70 to 100 feet below the surface in an area of about 80 square miles. As the Ogallala appears to be about 500 feet thick in some parts of this area, the zone of

saturation may be about 400 feet thick. The upland here is generally very flat, and the soils are excellent.[9] In some of the other shallow-water areas the water table is nearer the surface but the possibilities of successful large-scale irrigation appear to be less because the thickness of the Ogallala and of the zone of saturation in it are less, or because soils are sandy.

UNFAVORABLE AREAS.

There are also localities where a good well is uncertain. In the east-central part of Cimarron County the Ogallala formation is thin and dry because of a high ridge or hill on the pre-Ogallala topography (Fig. 1). Many wells have been drilled in this area, and most have encountered Triassic or Permian red shales at moderate depth. A few are reported to have obtained good supplies of water from the red beds, but most appear to have failed.

It is likely that a subsurface red-bed ridge extends from this locality in Cimarron County to the red-bed inliers in central Texas County, and that the higher parts of this ridge and of possible subsidiary ridges account for the erratic results reported by drillers who have worked in western Texas County.

In Beaver County there is a wide band along the south side of North Canadian River where most of the wells have been drilled in the Permian red shales. There are many wells in this area, hence a fair percentage of the wells drilled must be successful. However, the yield is generally small, the drawdown during pumping is very large, and the water commonly is so highly mineralized that it is used only for stock. Here cisterns filled with rain water or with water hauled from outside areas are the mainstay for domestic supplies.

OBSERVATION WELLS.

Measurements of depths to water level in about 100 wells in all topographic situations have been made bimonthly in Texas County since January 1938 and in the other two counties since July 1938.

[9] Fitzpatrick, E. G., and Boatright, W. C.: Soil Survey of Texas County, Oklahoma. U. S. Bur. Chem. and Soils, Series 1930, no. 28, pp. 15–17, and Map.

In deep wells on the uplands the total fluctuation in the water level has generally been less than a foot and heavy rains have had little observable effect. In shallow wells in the valleys, however, water-level fluctuations have been greater and significant rises have been observed after heavy rains. In most shallow wells the water levels in September 1939 were at the lowest stage since measurements were begun, probably because rainfall in the preceding 2½ months was considerably below normal.

EFFECT OF DROUGHT ON WATER TABLE.

The drought of 1931–39 seems to have affected the water table in alluvium more than in the Ogallala formation. Some wells in the valleys of the tributaries which enter North Canadian River from the south in Beaver County have failed, the flow of the more nearly perennial creeks has diminished, and deep water holes in other creeks have disappeared.

There are no previous measurements of water levels to furnish an adequate basis for comparison with the measurements made in the present investigation, but it seems that the dry years have had no serious effect on the water table in the Ogallala formation. At least there has been very little deepening of wells, and residents generally report little or no change in water level in their wells. However, in many windmill wells the cylinder is 10 feet or more below the static water level and a decline of several feet could have occurred without affecting the performance of the pump. That there has been some change is shown by the common report that many springs issuing at the Ogallala-Permian contact have dried up.

The flow of some of the springs issuing from the Dakota sandstone in Cimarron County also is reported to have diminished or to have stopped. This condition suggests that the water of the springs enters the Dakota at some nearby place rather than a distant one.

ACKNOWLEDGMENTS.

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U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
February 1, 1940.

A THEORY OF MINERAL SEQUENCE IN HYPOGENE ORE DEPOSITS.

MARK C. BANDY.

(Continued from last number.)

PART II.

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THE PARAGENESIS OF VARIOUS CLASSES OF ORE DEPOSITS—THEIR VARIATION FROM AND AGREEMENT WITH THE "NORMAL SEQUENCE."

A number of the general classes of hydrothermal ore deposits as described by Lindgren (27) and Graton (19) are considered in the following pages. General sequences for each class are given and the paragenesis of individual deposits is discussed in some cases. The sequences are viewed critically in each case from the viewpoint of their relation to the "normal sequence" advocated in this paper. Some of the data are taken from the literature but most are the result of the writer's studies. The successions given are based on textural relationships, combined in many cases with evidences exhibited in the field. The writer has sought to avoid bias in his sequence determinations but personal prejudices have undoubtedly entered the work in many places. Many of the sequences were determined before this theory was formulated.

Paragenesis of Magmatic Segregation Deposits.

If the premise is true that stable, deep-seated conditions promote a consistent paragenetic succession with few, if any, re-

versals, etc., that would be preserved in the deposits when exposed by mining, then the orthotectic and pneumotectic deposits (18) of close magmatic affiliations would be an ideal proving ground for the "normal sequence" theory. In this zone every condition approaches the ideal. These deposits give evidence of having been formed under conditions of prolonged stability at elevated temperatures and pressures. Temperatures dropped slowly during and following mineral deposition and the loss of pressure was slow but probably variable.

Using the term "magmatic segregation" in referring to these deposits implies a certain amount of migration. The migration is at a minimum in orthotectic deposits and increases in importance in pneumotectic deposits. The limitations to be put on the use of the term "magmatic segregations" are well known and no discussion is necessary. In recent years the tendency has been to decrease the number of deposits included under this class.

The "normal sequence" has been checked against the natural or actual sequence of a number of deposits and no differences were observed in the oxide succession and only a few minor differences in the sulphide succession. The deposits studied were: Sanford Lake, New York; Gap Mine, Lancaster, Pa.; Iron Mountain, Wyo.; Iron Mountain, R. I.; Macon Co., Ga.; Portiar Port Bay, Newfoundland; Megantic Co., Black Lake, and Sherbrooke, Quebec; Sudbury, Ont.; Atacama, and Copiapo, Chile; Sulitjelma, Evje, and Kragerö, Norway; Kiruna, Sweden; Great Dike (?), Rhodesia. No specimens of sufficiently diagnostic character have been available for the study of the platinum minerals and metals of the platinum group; some hand specimens were studied and a survey of the literature was made (11, 47, 48). The general sequence for this class of deposits is given below. In combining a number of individual sequences into a general sequence it is difficult to fit all minerals in their proper places, and some adjustment is usually necessary, although in the general sequence given below there was little or no adjustment. This sequence conforms with the "normal sequence."

THE GENERAL PARAGENESIS OF MAGMATIC SEGREGATION DEPOSITS.

Early	*Oxides*	Magnetite
		Hematite
		Ilmenite
		Rutile
	Sulphides	Löllingite
		Rammelsbergite
		Arsenopyrite
		Pyrite
		Pyrrhotite
		Pentlandite
		Cubanite
		Chalcopyrite
		(Sphalerite?)
		Bornite
Late		Galena

Minerals not Definitely Located in the Foregoing Succession

Early	Chromite
	Maucherite
	Sperrylite
Late	Platinum and the platinum group

The minerals in the second table could not be definitely placed in a general succession as they either occur alone, not associated with other metallic minerals, or they occur at the end of a metallization period. Chromite, for example, is rarely associated with other oxides and is commonly followed by pyrite. Sampson (31) does not mention any oxide or sulphide associated with chromite. The writer examined one specimen believed to be from the Great Dike, Rhodesia, that showed younger ilmenite associated with chromite but whether the chromite is older than hematite and magnetite is not known. The "normal sequence" would place it between hematite and magnetite. The following sequence relationships of maucherite from Sudbury were determined by textures:

Early	Rammelsbergite
	Maucherite
Late	Chalcopyrite

It is impossible to place maucherite in the general sequence from these relationships and this is the only occurrence that the writer has studied. Sperrylite is equally difficult to place. The "normal sequence" would place it as younger than pyrite and

maucherite and older than pyrrhotite. According to various authors platinum is younger than chromite and little else is known regarding its paragenetic relationships.

The age relationships of magnetite-hematite-ilmenite, and of chalcopyrite-sphalerite were determined in many cases on the basis of the interpretation given in this paper for exsolved textures. Exsolution blebs of hematite (not a grating texture) occur in some of the ilmenite but in every case examined the source of the hematite was interpreted as having been an earlier hematite that was strongly replaced and resorbed by the ilmenite. Gersdorffite, niccolite, cassiterite, molybdenite, etc., are mentioned in the literature as occurring in ores of this class but the writer did not observe any of them in the ores studied. The descriptions in the literature do not place these minerals in sufficiently definite sequence relationships to permit present discussion from that record.

In a few cases, textures of certain minerals indicate variations from the "normal sequence." This is particularly true in the ores of Sudbury. Nevertheless these ores agree, on the whole, with the sequence given above. Pentlandite occurs both before and after pyrrhotite, and by some the bulk of the pentlandite is placed after pyrrhotite; also some of the sphalerite earlier than pyrrhotite.

Paragenesis of Pegmatites.

The paragenesis of the metalliferous minerals of the pegmatites is difficult to establish in individual occurrences and the formulation of a general sequence for the class is proportionally difficult and uncertain. As a rule most of the metalliferous minerals are in large crystals, present in small quantities and unassociated with similar minerals. Vugs are common containing only one mineral or several minerals that lack mutual boundaries. In individual specimens where two minerals were associated, reversals and other departures of the actual from the "normal" sequence were not observed by the writer. Data regarding metalliferous mineral succession are not abundant as the literature deals primarily with the elements or non-metallic minerals in pegmatites.

The pegmatites that were studied in compiling the actual sequence of this group were: Etta Mine and Ingersoll Mine, South Dakota; Auburn, Paris, and Topsham, Maine; Quincy, Rockport, Townsend, and Winchester, Mass.; Middletown, Conn.; Kings Mountain, North Carolina; Boundary District, British Columbia; Ivigtut, Greenland; and various pegmatites of Norway and Sweden. Many of these pegmatites were studied through hand specimens and not polished and thin sections.

The general sequence determined for this class follows.

THE GENERAL PARAGENESIS OF PEGMATITES

Early	*Oxides*	Wolframite
		Cassiterite
		Magnetite
		Hematite
		Ilmenite
	Sulphides	Löllingite
		Arsenopyrite
		Pyrite
		Pyrrhotite
		Chalcopyrite
		(Sphalerite?)
Late		Galena

Minerals Not Definitely Located

Early	Tantalite
	Scheelite
	Molybdenite
	Bismuthinite
Late	Bismuth

Gold, stibnite, and jamesonite are reported in the literature as occurring in pegmatites but none of these minerals was observed in this study. Bismuthinite and bismuth were observed in hand specimens but from their spatial relationships they could be determined only as late minerals. Tantalite, scheelite, and molybdenite occurred in isolated grains.

Due to the wide range of temperatures under which the complex pegmatites form and the long and involved natural history which they have, pegmatites can carry oxides formed at elevated temperatures and sulphides and native elements formed at comparatively low temperatures. On the other hand, the uniformity

which they show in regard to sequence of metalliferous minerals is no doubt due, in part, to their long natural history. Any telescoping or reversals in sequence of deposition that they may have suffered at an early period would be entirely destroyed during the subsequent period. Most pegmatites have formed at such great depths and with such close magmatic affiliations that telescoping or reversals would not be expected. Regardless of the cause, the actual sequence determined from spacial relationships and textures is uniform, on the whole, and agrees with the "normal sequence" concept.

Tantalite occurs as the earliest mineral at Ivigtut, Greenland, and at Middletown, Connecticut. Hand specimens from the Etta Mine indicate that it is an early mineral, probably the earliest, and it is earlier than either rutile or pyrite at Amelia Courthouse, Virginia. Molybdenite is placed in the uncertain group because not enough occurrences were studied. The "normal sequence" would place it earlier than pyrrhotite; later than pyrite. In a vein of pegmatitic character near the Richards Mine, Dover, N. J., molybdenite was observed, younger than chalcopyrite. This disagrees with the "normal sequence." Thomson (42) gives no paragenesis for the molybdenite deposits of Quebec, and a few specimens from Enterprise, Ontario, give conflicting evidence on the paragenesis of molybdenite and pyrrhotite.

The sequence, wolframite-cassiterite-hematite disagrees with the sequence determinations in the literature of tin veins. Many tin deposits have pegmatitic characteristics and some tin deposits are placed in this class. The writer has had no opportunity to study a tin pegmatite in the field. At Araca, Bolivia, the cassiterite shows an increase in the amount of hematite in younger cassiterite, judged by the increase in depth of color.

The Paragenesis of Pyrometasomatic Deposits.

Pyrometasomatic deposits are those formed during the alteration of limestone and other reactive rocks near intrusive igneous masses usually of large size. In these deposits, more than in any other deep-seated, high-temperature and high-pressure de-

posits, the rôle of the wall rock is all important and its influence on the chemistry of ore deposition is most evident. Practically all of the material involved in the ore formation is introduced into the rock with the exception of CaO and other oxides derived from the replaced rock.

It has been established that CO_2 will readily oxidize ferrous iron at about 500° C., and above and below this temperature the power to oxidize decreases (9). Water will oxidize ferrous iron at about 600° C., but the tendency decreases at higher temperatures (12). If this reaction is applied to the chemistry of mineral deposition in pyrometasomatic deposits, it is evident that the tendency would be to form hematite and rutile in these deposits at the expense of magnetite and ilmenite. On the other hand, it has been proven in the laboratory that SO_2 readily reduces ferric oxide to ferrous oxide at temperatures up to approximately 350° C. (40), and the reaction may take place at even higher temperatures. However there is an upper limit, not far above 350° C. at which the reducing reaction stops.

On the basis of these data one could expect that the magmatic extracts, streaming off from the igneous source and passing through the surrounding rock, reacting with the carbonates, would produce a great quantity of CO_2. As the temperature drops to the neighborhood of 500° C. and CO_2 reacts with the ferrous oxide to form ferric oxide, hematite would be precipitated and magnetite would not be expected in any quantity.

Although hematite generally follows magnetite in pyrometasomatic deposits, many districts show a second generation of magnetite, usually where later sulphides border on hematite. The origin of this magnetite may be due to the action of SO_2. Such a reversal, magnetite after hematite, would be apparent in the light of the "normal sequence" theory. Without using this theory and lacking the aforementioned experimental data, how many workers would regard the sequence of magnetite after hematite as suggestive and requiring some explanation?

The general paragenesis of the pyrometasomatic deposits is as follows.

THE GENERAL PARAGENESIS OF PYROMETASOMATIC DEPOSITS.

Early	*Oxides*	Magnetite
		Hematite (specularite)
		Magnetite
	Sulphides	Pyrite
		Pyrrhotite
		Cubanite
		Chalcopyrite
		(Sphalerite?)
		Bornite
Late		Galena

This generalized sequence is based on the study of the following deposits; Cornwall, Pennsylvania; Bingham Canyon, Utah; Seven Devils District, Idaho; San Pedro, New Mexico; Bisbee, and Morenci, Arizona; Boundary District, Marble Bay Mine, Texeda Island, and Nickel Plate Mine, British Columbia; Cananea, Mexico; Langban, Sweden; and Tamaya, Chile.

Lindgren (27) and others mention magnetite as being both younger and older than hematite. Ilmenite, pseudo-brookite, and rutile are other oxides mentioned in the literature as being present in ores of this type but no definite statement could be found as to their relative age relationships and none was observed by the writer.

The sulphides show almost no differences between the actual and "normal" sequences, in the writer's experience. However, several divergent sequences are given in the literature and the writer has had no opportunity to check these. Many are given by competent workers. Uglow (45) and others describe bornite older than chalcopyrite and sphalerite is often placed older than chalcopyrite. Graton * would place sphalerite both older and younger than cubanite. Sphalerite containing exsolved blebs of chalcopyrite is common. A specimen from the Marble Bay Mine showed inclusions of galena in boulangerite but the age of the two minerals could not be determined definitely. According to the "normal sequence" boulangerite should precede galena. No specimens were studied that contained the three minerals bornite, sphalerite, and chalcopyrite so no data were obtained that would

* Personal communication.

place sphalerite definitely between chalcopyrite and bornite, as given in the general paragenetic summary.

Magnetite is in places later than the sulphides as at Vallenar, Chile, but the writer believes that there were two periods of mineralization, as the magnetite follows heavy fracturing. Butler (8) shows chalcopyrite replaced by magnetite, the latter occurring as rims about the sulphide grains. The writer has had no opportunity to study this deposit, San Francisco District, Utah, but it is conceivable that his texture may represent marginal rims of magnetite with centers of grains replaced by later chalcopyrite. Butler also determines the mineral sequence at the Cactus Mine, Utah, to be,

Early	Sericite
	Quartz
	Pyrite
	Chalcopyrite
	Tourmaline
Late	Hematite-magnetite

The writer would regard this as a very unusual paragenetic sequence. Tourmaline following sericite and chalcopyrite is certainly rare. If the theory of "normal sequence" be applied, tourmaline, followed by hematite and magnetite would indicate a reversal in mineralization with deposition at higher temperatures than those prevailing when the preceding sulphides were deposited. But there may be some other explanation for this case.

The Paragenesis of Hypothermal Deposits.

If hypothermal deposits are considered to be formed by direct continuations of the same processes that form orthotectic and pneumotectic deposits, but operating at greater distances from the source and at lower temperatures and pressures, then one would expect to find in this range of temperatures and pressures deposits that are more or less continuous with the more closely magmatic deposits. Progressive variations are to be expected and these variations would be reflected by the change from hypothermal to mesothermal types if the latter are regarded as deposited still farther from the source.

Graton (19) has advanced the concept of zoning within the hypothermal class of ore deposits; a useful aid in picturing the gradual change from one horizon of intensity to another within the hypothermal range. Graton has also emphasized, more than Lindgren did, the idea of gradation and continuity through all the hydrothermal zones.

As in the case of other deep-seated deposits, the actual paragenesis of the hypothermal deposits shows few divergences from the "normal sequence." Sequences are given in the literature that do not agree with the "normal sequence" but many of these are commonly based on textural criteria that have more than one interpretation.

To combine the actual sequences of the various individual deposits into a general sequence is difficult in this class of deposits because of the variety of minerals and the gaps that exist between the minerals of different deposits. The deposits studied by the writer were; Homestake, South Dakota; Latouche, Alaska; Dome, and Hollinger, Ontario; Rouyn, Quebec; Rossland, and Kimberly, British Columbia; Morro Velho, Brazil; Braden, and Los Condes, Chile. Also a number of Bolivian deposits were studied which are placed in this class by Lindgren and other writers. A discussion of ore deposit classification is outside the scope of this paper, but in the writer's opinion most Bolivian deposits, Braden, Chile, and other similar deposits do not fit into Lindgren's classification without modification. Rather than attempt a new classification or additions to the Lindgren classification, deposits such as Llallagua, Potosi, and Oruro, Bolivia will be classed as "telescoped deposits" (37, 19), deposits in which there is little agreement with the "normal sequence."

The generalized paragenesis of the hypothermal deposits is given below.

Scheelite is impossible to place precisely in any age relationship in the natural sequence. It is certainly an early mineral. It is widespread in many deposits but is commonly unassociated with other ore minerals. In Bolivian deposits with which the writer is familiar, scheelite is characteristically associated with barite, some

THE GENERAL PARAGENESIS OF HYPOTHERMAL DEPOSITS.

Early	*Oxides*	Wolframite
		Cassiterite
		Magnetite
	Sulphides	Arsenopyrite
		Pyrite
		Pyrrhotite
		Pentlandite
		Chalcopyrite
		(Sphalerite?)
		Stannite
		Tetrahedrite-tennantite
Late		Galena
Minerals Not Definitely Placed		
	Early	Scheelite
		Hematite
		Molybdenite
		Bornite
	Late	Gold

ankerite and traces of quartz. There is a need for the study of the depositional environments of scheelite and wolframite. Hematite is difficult to place in this type of ore deposit. Bateman (6) found it a difficult mineral to place in relation to cassiterite in the paragenesis at Slocan, British Columbia.

Molybdenite is a common mineral in many hypothermal deposits but it is generally present in such small amounts that the exact age relationship with other sulphides is hard to establish. In the literature it is regarded as an early mineral by some, although other writers describe it as a late mineral and apparently regard this as its normal position. It is an early mineral at Cananea, Mexico, and Bagdad, Arizona.

The relationship of stannite-sphalerite-bornite is equally difficult to establish. Since stannite carries inclusions of chalcopyrite and sphalerite it is regarded by the writer as later than the main period of these minerals. In the ores of Cornwall, England, stannite is later than sphalerite, while at Colquechaca, Bolivia, a "telescoped deposit," sphalerite is both earlier and later. In a paper describing a stannite ore from Tasmania, Stillwell (38) definitely places stannite between chalcopyrite and tetrahedrite.

Tellurides occur in some hypothermal ores, as at Hollinger and other Canadian mines, Australia, etc. The writer had no opportunity to study adequate suites of any of these telluride ores and information obtained from the literature is inadequate. The only relationship that the writer could establish was that they are younger than pyrite and older than gold. Stillwell (39) has described the tellurides and other minerals present in the ores of Kalgoorlie in an elaborate paper. He carried out a very careful study on a large suite of ores and identified 27 ore minerals, many of them rare. Unfortunately he ended with such complex age relationships between the various minerals that he made no attempt to give any systematic sequence. One feature that complicated his work was the occurrence of many tellurides that he regarded as supergene and others that were both supergene and hypogene. Others he regarded as uncertain whether supergene or hypogene. The writer sought to obtain the suite of specimens for study but because of their high gold content and resulting high price was unable to do so. The ores of this district would make an ideal proving ground for the theory of "normal sequence."

During the present study, an attempt was made to assemble a paragenetic suite of selenide ores from Skrikerum, Sweden, but the only specimens that the writer obtained were of individual minerals that showed no paragenetic relationships.

The Paragenesis of Mesothermal Deposits.

Since the mesothermal zone occupies a position between the hypothermal and the shallower leptothermal and epithermal zones, there appears to be a tendency to place in this group all deposits that do not develop features characteristic of the lower or higher zones. However, the type deposits are well defined and have certain paragenetic characteristics that are diagnostic of the zone.

The actual paragenesis of mesothermal deposits shows many disagreements with the "normal sequence"; in fact, agreements are not more than 50 per cent, probably less. Oxides are not common but deposits placed in this class are reported to contain

wolframite and the writer has observed specularite and magnetite. The following deposits were studied: Butte, Montana; Coeur d'Alene, Idaho; Grass Valley, California; Leadville, Colorado; Tintic, and Park City, Utah; Ely, Nevada; Magma, and Jerome, Arizona; Premier Mine, British Columbia; Cobalt, Ontario; Cananea, Mexico; Cerro de Pasco, Peru; Chuquicamata, Collahuasi, Tramaya, Coquimbo, Romulo, and Tocopilla, Chile; Tsumeb, South Africa.

It is quite impossible to give a comprehensive general paragenesis for the mesothermal deposits. They vary widely as to mineral and metal content and since many of the ores are copper or silver ores, enrichment effects are very pronounced and one would judge from the literature that many supergene copper minerals have been incorporated in hypogene mineral successions in various deposits. Chalcopyrite is both a hypogene and a supergene mineral and appears in the literature in many successions in unusual age relationships. Chalcocite has undoubtedly been included in the list of hypogene minerals of districts where it is actually supergene and visa-versa. Whether the chalcocite is hypogene or supergene, it would be a late mineral so the difficulty here is not as serious as it is with chalcopyrite.

Butte, Montana is an example of this class of ore deposit. A deposit as large and varied as this cannot be investigated by specimens alone; long field study would be necessary to give adequate background to discuss the district critically; this, the writer has not had. But a few points will be mentioned. There is little agreement in the literature on the paragenesis of the district and this is not surprising. Lindgren (27) gives the sequence for Butte as, pyrite (oldest), sphalerite, enargite, tennantite, bornite, chalcopyrite, and chalcocite (youngest). If this sequence is accepted, one must recognize that there are certain reversals of the usual order of mineral deposition, for example, tennantite before chalcopyrite and bornite. Examining the problem from the viewpoint of the "normal sequence," and following that theory alone, without knowledge of the field relationships, one would conclude that there was an orderly decrease in temperature to the tennantite period followed by a gradual rise in temperature to the

chalcopyrite period and then a drop in temperature during the chalcocite period. Obviously, a sequence established in this manner would need support from field and laboratory work, especially the finding of evidence for or against the idea of a fluctuating temperature. It is reasonable to expect a rise in the geothermal gradient, especially in the center, of so large a district during a long period of transfer of material from the magmatic source. Fracturing at the end of the enargite period or during the tennantite period would support the "normal sequence" interpretation.

PARAGENESIS OF BUTTE, MONTANA (AFTER LINDGREN).

		Cation.				Anion.	
		Fe%.	Zn%.	Cu%.	As%.	S%.	
Early	Pyrite	46.6				53.4	Decreasing temperature
	Sphalerite		67.0			33.0	
	Enargite			48.3	19.1	32.6	
	Tennantite			57.5	17.0	25.5	
	Bornite	11.1		63.3		25.6	Increasing temperature
	Chalcopyrite	30.5		34.5		35.0	
Late	Chalcocite			79.8		20.2—Decreasing temperature	

A different association of minerals is shown at Chuquicamata, Chile. A detailed study, both in the field and laboratory showed the following succession.

PARAGENESIS OF CHUQUICAMATA, CHILE.

Early Fracturing
Hematite
Magnetite
Pyrite
Several periods of fracturing with introduction of pyrite
Pyrite
(Molybdenite)
Chalcopyrite
Bornite
Fracturing
Enargite
Late Covellite
Supergene Alteration

Sphalerite and tetrahedrite are present in insignificant quantity. Covellite is present as a supergene product but some of the covellite, intimately associated with the enargite, is certainly hypogene. Chalcopyrite and bornite are not uncommon in the ores of the outlying veins. Specimens from veins along the north edge of the deposit show chalcopyrite definitely replaced by bornite. Following a period of fracturing, enargite was introduced and it strongly replaced bornite and chalcopyrite. It is the writer's belief that enargite replaced all, or practically all, of the bornite-chalcopyrite in the central area of the deposit.

The chalcopyrite-bornite-enargite sequence is tabulated below.

		Cation.			Anion.
		Fe%.	Cu%.	As%.	S%.
Early	Chalcopyrite	30.5	34.5		35.0
	Bornite	11.1	63.3		25.6
Late	Enargite		48.3	19.1	32.6
	(Covellite)		66.4		33.6

This succession does not agree with the "normal sequence." If one grants the hypothesis that there is a rough relationship between age and temperature of deposition of minerals, i.e., that the later minerals in a vein are deposited at lower temperatures than the earlier minerals, then an explanation offers itself for the lack of agreement just cited. During the pyrite-chalcopyrite-bornite period of mineralization there was a gradual rise in the geothermal gradient in the center of the deposit. Fracturing opened new channels and enargite was deposited at higher temperatures than bornite. Covellite, a mineral present in the deposit in minor amounts, offers supporting evidence to this interpretation.

According to the interpretation of the sequences at Butte and Chuquicamata, from the viewpoint of the "normal sequence" theory, there was a gradual rise in temperature during the mineralization period of both deposits. The writer is unfamiliar with the Butte ores, but there are no field or laboratory data

known to the writer that are inconsistent with the interpretation offered for Chuquicamata.

Magma, Arizona, is an example of a deposit with a similar type of mineralization but one that agrees with the "normal sequence." The ore contains chalcopyrite-bornite-tennantite with enargite as a rare constituent. Short and Ettlinger (36) state;

> (enargite) . . . is evidently rare in the Magma Mine. The conditions of deposition were, in general, such as to favor the precipitation of the arsenic as tennantite rather than enargite.

No statement is made as to what the conditions of deposition were; they place chalcopyrite as the earlier mineral with no essential age difference between bornite and tennantite. The writer believes that tennantite (and not enargite) is a "normal" mineral that forms in the "normal" and "ideal" deposit, after bornite.

		Cation.			Anion.
		Fe%.	Cu%.	As%.	S%.
Early	Chalcopyrite	30.5	34.5		35.0
	Bornite	11.1	63.3		25.6
Late	Tennantite		58.0	17.0	25.0

At Cananea, Mexico, the age of the sphalerite is uncertain. It contains exsolution blebs of chalcopyrite and in some places occurs along fractures in galena, apparently younger than the galena unless the veins are antecedent. Some of the sphalerite is conspicuously free from exsolution chalcopyrite, while an apparently older sphalerite is characteristically filled with it. Can this younger sphalerite represent a late deposition at a temperature too low to have incorporated an exsolvable excess of copper?

The deposit at Cerro de Pasco, Peru, is complex, with ore deposition held to be, in part, from acid solutions. The writer is unfamiliar with the deposit and it is not discussed here. The ores of Cobalt form an interesting group usually placed in this class although it is doubtful if they belong here, strictly speaking. The ores are complex and detailed paragenesis is apparently dif-

ficult to establish. This district might be a good proving ground for the "normal sequence" theory. Detailed field work as well as a very extensive ore suite would be necessary to test the theory adequately. A great deal of work has been done already on the area (2, 4, 23, 44, 51). The most recent work by Thomson (44) is of little use for present purposes as he expresses his results in terms of relative abundance of the various minerals at different depths and gives little information as to mineral sequence. Bastin (4) studied the ores of South Lorraine but did not arrive at a detailed paragenesis. It is of interest that the first suite of ore minerals to be studied by means of vertical illumination on polished surfaces was from Temiskaming (10). The paragenesis as determined by Thomson for Cobalt and by Campbell and Knight for Temiskaming are given below with the "normal sequence" for comparison.

Paragenesis of Cobalt, Ontario (after Thomson)	*"Normal Sequence"*
Smaltite-chloanthite-skutterudite (Early)	Skutterudite
Cobaltite-gersdorffite	Löllingite
Safflorite-rammelsbergite-löllingite	Smaltite-chloanthite-safflorite-rammelsbergite
Arsenopyrite-pyrite	Arsenopyrite
Niccolite-breithauptite	Cobaltite-gersdorffite
Fracturing	Breithauptite
Silver-dyscrasite-argentite-bismuth-bismuthinite-cosalite	Niccolite
Galena-sphalerite-chalcopyrite-pyrrhotite-tetrahedrite-marcasite	Pyrite
Pyrargyrite-proustite-staphanite-silver (Late)	Pyrrhotite
	Chalcopyrite, etc.

Paragenesis of Temiskaming, Ont. (After Campbell & Knight).	*"Normal Sequence"*
Smaltite (Early)	Smaltite
Niccolite	Niccolite
Argentite	Argentite
Silver	Silver-bismuth
Bismuth (Late)	

Some years ago the writer studied the Romulo Mine, a small deposit near Toco, Chile. The sequence determined for this mine was skutterudite (early), smaltite, chloanthite, niccolite, etc. (late). This agrees with the "normal sequence" and was determined before the writer conceived the idea of a "normal sequence."

A study by Lausen (25) of a graphic intergrowth of chalcopyrite and niccolite from the Sudbury District, said to be formed by replacement, shows that the arsenides and similar minerals precede the sulphides, as a rule. Lausen's paragenesis for the Worthington Mine is; gersdorffite (early), niccolite, maucherite, and chalcopyrite (late). This is in complete agreement with the "normal sequence."

Uglow and Osborne (46) describe a gold-cobaltite-lodestone deposit in British Columbia and arrive at the following paragenesis for the occurrence.

	Actual Sequence	*"Normal Sequence"*
Early	Magnetite	Magnetite
	Pyrrhotite	Cobaltite
	Pyrite	Pyrite
	Cobaltite	Pyrrhotite
	Chalcopyrite	Chalcopyrite
	Gold	Bismuthinite
	Bismuthinite	Gold-bismuth
Late	Bismuth	

This sequence is at wide variance with the "normal sequence" and the latter is useless in explaining the variations without postulating a very involved history of several periods of fracturing with variations in temperature. The method used by the authors for determining the age relationship of the gold is open to some criticism. They suggest that since relatively more gold than bismuth minerals were formed contemporaneously with the chalcopyrite, the gold began to deposit before the bismuthinite and bismuth.

The paragenesis of the Sierra Nevada gold ores is poorly described and as a rule poorly understood, apparently. This is unfortunate as they represent deep-seated deposits which formed under uniform conditions throughout the deposits. A recent report by Ferguson and Gannett (15) lists the following minerals from the Allegheny District: rutile, pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, tetrahedrite, galena, jamesonite, and gold. They place the jamesonite earlier than galena, a disagreement with the "normal sequence." Knopf (24) described seven-

teen ore minerals from the Mother Lode of California but descriptions of the age relationships of the various minerals are almost entirely lacking. Hulin (21) describes a suite of specimens from the Kennedy Mine of the Mother Lode and established the following succession on the basis of high-grade specimens from a single level of the mine: pyrite (early), sphalerite, galena, chalcopyrite, and gold (late). Early pyrite and late gold are the only agreements with a "normal sequence." He described chalcopyrite as intimately associated with pyrite and occurring as blebs in sphalerite.

Lindgren (27) gives the following sequence for mesothermal deposits in general and states: "The sulphides usually form in the following order, exceptions from this sequence being rare." For comparison with the rather rigid sequence of Lindgren, the sequence determined by Buschendorf (7) for the gold-quartz veins of this class is also given.

Paragenesis of Mesothermal Deposits (After Lindgren)	*Paragenesis of Gold-Quartz Veins (After Buschendorf)*
Pyrite	Pyrite
Arsenopyrite	Arsenopyrite
Co-Ni arsenides	
Pyrrhotite	Sphalerite
Sphalerite	Pyrrhotite
Enargite	
Tennantite	
Tetrahedrite	
Bornite	
Chalcopyrite	Chalcopyrite
Galena	Gold
Argentite	Galena
Gold	Stibnite-sulpho-salts-tellurides
Sulpho-salts of Au and Ag	Marcasite

The Paragenesis of Leptothermal, Epithermal, and Telethermal Ore Deposits.

Any attempt at a generalization of the actual paragenesis of these ores would be difficult and in the light of the "normal sequence," useless. In the writer's experience all the deposits of this class show variations from the "normal sequence." They also vary widely among themselves. On the basis of the theory

herein advanced, this is to be expected. Variations in the rate of flow of solutions in the conduit due to obstructions and temporary damming of the flow would have a marked effect on the mineral sequence in the ores formed in these upper zones. The rate of flow of solutions, the volume, and the temperature would fluctuate widely and sharply during metallization. These variations might be rhythmic. From other evidence than the ore minerals, it is believed by some that the ore solutions from which many epithermal ores were deposited may have been acid during part of the metallization period, and it has been suggested that this acidity might have been brought about by a more rapid drop in pressure than temperature. It is hardly to be doubted that solubilities in acid solutions would differ from what they are in alkaline solutions.

There is no point in quoting a series of sequences of ores of these classes. The agreements with the "normal sequence" are few. This lack of agreement would mark the ores as either telescoped or as being formed near the surface, according to the theory. However the writer believes that the theory would be of use in interpreting the history of these deposits, since disagreements should be just as significant as agreements.

It is unfortunate that almost all the selenide ores come in these classes. Their paragenesis, as stated before, is almost unknown. At Republic, Washington, the sequence of some of the minerals is: chalcopyrite (early), coloradoite, gold, and an unidentified selenide (late).

SUMMARY.

In the preceding section the agreements and disagreements between the actual sequence and the "normal sequence" in various classes of ores were presented to the best of the writer's ability. The extent to which personal prejudice has entered this comparison can only be judged by others. The writer feels that personal prejudices have played a very prominent rôle in many sequence determinations by different workers and it has undoubtedly operated unconsciously in the case of the present writer.

There are a number of features of actual mineral successions that are difficult to reconcile with the "normal sequence" theory and a few of these will be pointed out.

Sphalerite.—Sphalerite is probably the most difficult mineral to reconcile with the theory, and, at the same time, it is an important ore mineral, common to the majority of ore deposits. There are relatively few hypogene zinc-bearing sulhpides. In the majority of the mineral sequences given in the literature, sphalerite occurs with iron and copper sulphides. Its usual precedence of chalcopyrite, according to the literature, has been indicated in various sections of this paper. If it occurred in the average sequence in the position it should occupy according to its anion percentage composition, it would interrupt the deposition of both iron and copper, as for example between chalcopyrite and bornite. The only position it could occupy and be consistent with the "normal sequence" theory would be after covellite or chalcopyrite and before copper-free lead minerals. This mineral may invalidate the idea expressed herein that once a metal starts to precipitate from an ore solution in a "normal" deposit, it continues to precipitate without interruption until it is all removed. It should be pointed out that one probably finds more divergence of opinion regarding the paragenetic position of this mineral than of any other. The treatment of this sphalerite is one of the weak points of the theory and additional, critical work is needed.

Enargite.—Enargite in large and important deposits such as Butte, Montana, and Chuquicamata, Chile, occurs in paragenetic relationships that do not agree with the "normal sequence." The theory is advanced in the section on Mesothermal Deposits that the mineral is deposited under conditions of increased temperature. The significance of this mineral can only be determined after a comparative study has been made of the depositional environments of enargite and tennantite in a number of deposits.

Dimorphous Minerals.—Adhering to the theory, the minerals of any dimorphous or trimorphous group all have the same position in a mineral sequence. A study of actual sequences soon shows that this is contrary to facts. The three most common dimorphous pairs of ore minerals are pyrite-marcasite, sphalerite-

wurtzite, and argentite-acanthite. The writer has had little experience with wurtzite and has seen acanthite only in mineral specimens and one or two polished sections, never in the field.

It is significant that marcasite and wurtzite often occur together in the same deposit. At Llallagua, Bolivia, wurtzite is a rare mineral and marcasite common while the reverse is true at Carguaicollo, Bolivia. Pyrite and sphalerite also occur in these ores. Insufficient laboratory work has been carried out to establish definitely the sequence relationships of these dimorphous groups. At Cuyuma, Bolivia, marcasite was definitely established, in the field, as the youngest sulphide in some veins. At Montserrat, Bolivia, marcasite occurs as a late mineral, pseudomorphic after calcite, and apparently later than wurtzite. At Llallagua and Carguaicollo wurtzite and sphalerite occur together and the wurtzite probably follows the sphalerite.

It is generally believed that wurtzite and marcasite are deposited from solutions that are either acid or unusually low in alkalies. The deposits containing these minerals with which the writer is familiar are all high-temperature, near-surface, telescoped deposits, deposits which most probably have formed, in part, from acid solutions.

The writer's experience indicates that marcasite can form as a late mineral; after early iron sulphides have been followed by iron-free minerals. An explanation suggests itself. In acid solutions, as contrasted to alkaline solutions, the order of deposition is reversed. This is certainly true at Carguaicollo where the general sequence is,—

		S%
Early	Teallite (pufahlite)	16.4
	(Cassiterite?)	
	Wurtzite	33.0
Late	Marcasite	53.4

The bulk of the wurtzite is later than teallite. Cassiterite occurs in minute quantities and its age could not be determined in the field. It is certainly later than teallite. The paragenesis of other minerals, franckeite, cylindrite, jamesonite (?), etc. was not established.

It should be recognized that in dealing with the less common member of these dimorphous groups we are dealing with relatively rare minerals, minerals that are in themselves diagnostic of abnormal depositional environment.

Strong and Weak Anions and Cations.—The theory, as expressed in this paper, lays equal stress on all anions. Undoubtedly some of the anions are stronger, chemically, than others, yet the writer cannot weigh the effect this may have on the "normal sequence" theory. A more complete and critical field and laboratory study of deposits with arsenides, antimonides, bismuthinides, etc., is needed. Here again the need of critical studies of telluride and selenide deposits is felt. Deposits of sulpharsenites, sulphantimonites, etc., might throw light on this subject and it is unfortunate that these minerals are comparatively rare in deep-seated deposits. If we consider the three sulphominerals tennantite ($3Cu_2S \cdot As_2S_3$), tetrahedrite ($3Cu_2S \cdot Sb_2S_3$), and wittichenite ($3Cu_2S \cdot Bi_2S_3$) in the light of the "normal sequence" we find that they should be deposited in the order named, early to late. This is probably the order of their strength as cations. In the writer's work he has found no definite evidence of the effect of strong and weak anions and cations on the general paragenesis.

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LLALLAGUA, BOLIVIA,
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DISCUSSION AND COMMUNICATIONS

RADIOACTIVE STANDARDS.[1]

Sir: A series of radioactive standards is being prepared under the direction of the Committee on Standards of Radioactivity of the National Research Council. These standards will be deposited at the National Bureau of Standards in Washington, D. C., to be issued as working standards to investigators who may desire them.

The standards under preparation at present are:

(1) Radium Standards

(*a*) 100 c.c. solutions sealed in 200 c.c. Pyrex flasks containing 10^{-9} and 10^{-11} grams of radium to be used as emanation standards either directly or by subdilution.

(*b*) 5 c.c. solutions sealed in Pyrex ampoules containing 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10, 20, 50 and 100 micrograms of radium to be used as gamma ray standards. If desired, these may be obtained in sets of 13 with two each of the 0.2, 2, and 20 microgram standards.

(2) Thorium Standards

Sealed ampoules containing sublimed $ThCl_4$. These may be used in preparing standard thorium solutions. Directions for use will be furnished with the standards.

(3) Standard Rock Samples

The following rocks, ground to pass 40-mesh screen and be retained on 100-mesh screen are available in 100 gram samples.

Quartzite (Virginia)
Triassic diabase (Virginia)
Milford granite (Massachusetts)
Chelmsford granite (Massachusetts)
Gabbro-diorite (Massachusetts)
Columbia River Basalt (Idaho)
Berea sandstone (Ohio)
Dunite (North Carolina)
Carthage granite (Missouri)
Carthage limestone (Missouri)
Deccan Trap (India)
Kimberlite (South Africa).

[1] This work is being supported in part by a grant from the American Philosophical Society to the Massachusetts Institute of Technology.

These samples of rock will be analyzed for radium and thorium content and are intended for use as working standards to check methods used in extraction of radon and thoron from rock samples. They may be used for direct fusion in the electric furnace or for carbonate fusion.

All of the above samples will be analyzed at a number of laboratories equipped to make such measurements and ultimately certificates will be issued by the National Bureau of Standards. This work is in progress but will require considerable time for its completion so that final figures are available only for a part of the samples at the present time.

Accurate knowledge of the radioactive content of the materials of the earth's crust is of primary importance in many phases of geology, geophysics and cosmology. Reliable radioactive standards are also essential in studies of radium and thorium poisoning and in biological and medical investigations using the technique of radioactive indicators, or internal artificial radioactivity therapy. For the latter purposes calibrated standard sources of β-rays will be made available.

It is hoped that the standards which have been prepared by the Committee will provide all workers in these fields with a common basis for comparison of measurements and also improve the accuracy of all measurements of this type. It is likely that they will have other applications and the Committee would appreciate hearing from interested persons who may desire similar standards for their work. The Committee is also glad to cooperate as far as possible in aiding investigators to use these standards to the best advantage and welcomes specific inquiries regarding their use. It is urged that any suggestions regarding other desirable radioactive standards, not at present available, be submitted promptly to the Committee. In particular, it will facilitate the work of the Committee if those laboratories and individuals which can make use of these standards advise the Committee of their probable requirements.

Communications may be addressed to the Chairman, Professor

Robley D. Evans, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

L. F. Curtiss,
Clark Goodman,
Alois F. Kovarik,
S. C. Lind,
C. S. Piggot,
Robley D. Evans,

REVIEWS *

Adirondack Igneous Rocks and Their Metamorphism. By A. F. BUDDINGTON. Pp. 354; Pls. 21; Figs. 30. Geol. Soc. America, Memoir 7, 1939.

It probably is presumptuous of one who is merely an economic geologist and in no sense a petrologist to attempt a review of this monographic volume. But as a resident familiar in some detail with a small portion of the area covered, and having some knowledge of the years of toil and reflection that are distilled into its description, I set down this appreciative, even if not always uncritical appraisal.

Here are presented, the author states, the essence of more than 24 months of continuous field work spread over more than 24 years; supplemented by the study of more than 3,000 thin sections, and by 97 new complete rock analyses, to which are added for comparison 82 that are republished; all this involving, as the author does not state, many months of additional labor by himself and others.

Drawing freely upon the detailed studies of the earlier specialists in Adirondack geology, particularly Kemp, Cushing, Smyth and Miller, as well as on later students, including notably himself, Alling and Balk; always liberal in giving credit to a previous worker and consideration to his views even if found unacceptable; this book literally brings Adirondack geology out of the horse and buggy days into the era of the automobile, for in the later 10 years much of the field work has consisted in touring many miles of previously studied territory checking and rechecking doubtful or conflicting evidence and gathering additional data for interpretation, a task wholly impossible in earlier days. The long time interval represented by the work has also the great merit that it has permitted many ideas to be tried, tested and proved, or rejected in favor of better ones. At the outset I submit only one serious criticism as to presentation. The illustrations involving maps are well conceived as to content but poorly done with respect to lettering and relation to the degree of reduction. On nearly all line drawings it is necessary to use a reading glass. The patterns are not always as clear as might be, and details are

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

overcrowded. The tabulations are numerous and clear, however, and the photographic plates of polished rocks and of thin sections are exceptionally good.

A very readable and complete abstract precedes the full presentation. Clearly admitted is the existence of large gaps in the detailed knowledge of the central Adirondacks, necessitating inference from incomplete evidence. An excellent bibliography is included.

Classification of Igneous Rocks.—Broadly, the Adirondack igneous rocks are grouped as follows in age and importance:

All Capped by Paleozoic

Keeweenawan { Basaltic Dikes

ARCHEAN {

Pegmatites

GRANITE { ALEXANDRIA, ANTWERP, HERMON } TYPES

Hypersthene Meta diabase

QUARTZ SYENITE (of numerous facies)

GABBRO, ANORTHOSITE } Co-Magmatic

All cutting Grenville

This grouping, it may be noted shows none of those extensive volcanics, commonly altered to amphibolites, which the Canadians describe as interbedded with the Grenville in southern Canada, apparently supplanting the limestone so prominent in New York. Somewhere south of Madoc and Shawinigan Falls lies a major unsolved problem in the Grenville. This problem is mentioned but not elaborated.

Buddington's grouping simplifies the earlier postulates of different field workers in two important respects. The gabbros, variously placed as both older and younger than the anorthosite, are all declared younger on the basis of what seems to be acceptable field evidence. Likewise the granites, sometimes classified as Laurentian and Algoman, perhaps from too closely following Canadian analogies, are placed in one consanguineous group on evidence that seems good and agrees with the reviewer's observations.

Anorthosite.—The anorthosite, forming a somewhat asymmetric core east of the center of the Adirondacks, is interpreted as an injection, probably in complex laccolithic form, into flatlying Grenville, with large outlying sheets. It is assumed to have come from a magma of approximately the average composition of the present anorthosite plus gabbro, a conclusion that may not find favor with some petrologists either on the basis of

theory or experiment, but at least with the merit of sticking to the obvious. Segregation and differentiation are used to account for the gabbro and for many intrusive relations, including the mooted ilmenite-magnetite iron ores *up to a certain point,* but not too far. Unfortunately this problem is hidden in a discussion of mafic metagabbros (pp. 64–67) and cannot be located by name in either the table of contents or the index. (Note: Non-titaniferous magnetites come later.)

Syenite.—Around the margins of the main igneous core are belts of syenitic rocks varying from the median of pyroxene quartz-syenite to abundant hornblende granite at one extreme and limited masses of shonkinite rich in ilmenite-magnetite at the other. These variations are attributed, on the basis of extended chemical and petrographic study, to gravity differentiation of a mild type. The Diana complex, some, 30 miles long, 5 miles wide, and hook shaped is divisible into 8 bands of varying width, most acid at one side, most basic a little off the median line. It is strongly tilted parallel to the bordering Grenville, which it intrudes, and is interpreted as an overturned isoclinal synclinally folded sheet. The 5-mile-wide belt (true thickness about 3.5 miles) evidently is exactly half the supposed syncline, the rest being cut out by later granite. This half is assumed to be overturned.

Even though this interpretation makes the adjoining Grenville into an overturned anticline, thereby agreeing with the reviewer's conclusions in an adjoining area, there seem to be serious difficulties in accepting it wholeheartedly. This enormous sill (3.5 to 4 miles thick of solid syenite and granite) is assumed to have been intruded into nearly flatlying Grenville beds and subsequently folded along with those beds as if it were paper, into a tight isoclinal fold! In addition to the dynamic difficulties, some supporting field corollaries seem lacking. This gigantic sill, if such it was, possesses few if any recognizable offshoots or equivalents in adjacent Grenville territory except in a narrow belt usually 3 to 5 miles wide near its margin, even though Grenville beds demonstrably higher than the plane of contact occupy wide areas not many miles away. It seems to the writer that other possibilities should be desperately sought. The author does entertain the idea of successive sheet-like surges from a mass differentiating at greater depth. Incidentally, the evidence of differentiation, chemical and mineralogical, although very definite, seems to the reviewer considerably less extreme than might be expected from the free cooling and differentiation of a sheet of such unusual thickness solidifying in anything like a horizontal attitude.

Granite. Widespread granite masses interpreted as batholithic cut the syenite and anorthosite and involve remnants of Grenville throughout the Adirondacks. Also, in the bordering Grenville belts are many outlying relatively small bodies which occur in sill-like or phacolithic and occasion-

ally irregular masses. Where intruded into limestone they incline to be lean in quartz, attributed to the escape of quartz and mineralizers into surrounding limestone, producing syenitic facies in the intrusive. A major grouping of these granites into porphyritic (Hermon type) and non-porphyritic (Alexandria) is well-defined, but is interpreted, reasonably in this reviewer's opinion, as significant of only a slight age difference, the fine-grained type probably being later, and nearly always phacolithic.

Pegmatites are abundant both in the granites and their environs, and where intruded (?) into limestone result in unusual facies, generally characterized by discontinuity of form and depletion in quartz, the latter assimilated into the host. This feature is so pronounced that the theory of pegmatite introduction by replacement rather than injection is treated with some favor, though not fully accepted. The writer's own experience suggests that injection of a highly fluid magma was followed by excessive reaction with the wall rock resulting in disconnected nodular relics of highly feldspathic pegmatite surrounded by aureoles of intense silication. Here is a fertile field for study.

Economic Geology.—Closely related to the granites is most of the economic geology of the region, beginning with pegmatites that have been mined as feldspar deposits. The two notable zinc mines of the Edwards district, in Grenville limestone, are attributed to thermal solutions from granite residuals, definitely post-pegmatite. Here also are placed the formerly commercial pyrite replacements of Grenville gneisses. All these are situated in belt of prevailing Grenville with subordinate granite. The talc deposits of the same locality are referred to hydrothermal alteration of tremolite masses, slightly later than the sulphide deposits.

Also referred to the granite, but in the batholithic areas, are the nontitaniferous magnetite ores, regarded as thermal replacements of included and highly altered Grenville gneisses. Treatment of all these subjects is very brief, but acceptable to the reviewer. The economic garnet and graphite deposits scarcely are mentioned, except as incidents of metamorphism.

Structure.—All of the older igneous rocks of the region (even including the 4-mile-thick syenite sill) are assumed to have been intruded into nearly flatlying or only slightly folded sediments, whereas nearly all the extreme and complicated folding of this complex region, is attributed to a period of deformation coinciding with the emplacement of the granites. This seems to the writer open to some doubt. In the first place the emplacement of large intrusions of any age must almost necessarily cause considerable deformation and disturbance, somewhere, and for some local masses of gabbro in the Grenville belt this seems apparent. In the second place, had the great Diana syenite actually been emplaced as a thick sill, and

then folded, it seems to the writer that the resulting disturbance and dislocation along the syenite-Grenville contact should have been intense, and could never have left these very dissimilar rocks in their existing attitude of near conformity.

Metamorphism.—The subject of metamorphism, from all angles, is treated in excellent detail and convincing manner, albeit this section is rather heavy going for an economic geologist. Those who have followed at all the recent trend in this field may be surprised at the complete absence of petrofabric charts or Sanders technique, an omission admitted by the author, not greatly regretted by the reviewer.

In general, the contact type of metamorphism is found particularly around anorthosite-Grenville contacts, and at places where the latest (Alexandria type) granite intrudes Grenville of limey character. No ore deposits result, though non-metallics (garnet, wollastonite) may have a slight interest.

The regional metamorphism, attributed mainly to the tectonic disturbances preceding and accompanying the granite, is divided into four intensity zones. Most of the gneissoid features, even of the more massive igneous rocks, are ascribed to dynamic forces rather than to molten flow, and seemingly convincing evidence is presented.

Conclusion.—One omission regretted by the reviewer, is the lack of any data on, or discussion of, the determination of rock ages by the radium and helium methods, a subject on which some work is understood to be in progress.

The more abstruse topics such as gravity differentiation and dynamic metamorphism usually are elaborated or explained in reasonably elementary fashion and illuminated by comparisons drawn from worldwide sources.

JOHN S. BROWN.

EDWARDS, N. Y.,
May 8, 1940.

Catalogue of Topographic and Geologic Maps of Virginia. By JOSEPH K. ROBERTS AND ROBERT O. BLOOMER. The Dietz Press, Richmond, Virginia, 1939, 246 pages.

Though bearing the prosaic and modest designation of a "catalogue" this book is much more than a catalog of maps. It is a history of the development of the science of geology in Virginia as revealed by Virginia maps. Virginia has played such a prominent rôle in the development of the science of geology in the United States, that this history serves as an indicator of the development of the science in the United States, particularly during the nineteenth century. Very appropriately the authors dedicate the book to the memory of William Barton Rogers whose life spanned

the years from 1804 to 1882, and whose contributions to the geology of Virginia made him one of the outstanding geologists of the preceding century.

Once in a while an unselfish individual pauses in his work of contributing new material to science and presents a summary and analysis of that which has been done. This reveals to his fellow workers the background of existing scientific knowledge and makes them more appreciative and more cognizant of what they owe to those who have toiled before them. When that task results at the same time in a complete and comprehensive listing of existing maps, something of practical use also has been made available to his fellow workers. Such a commendable task has been completed by Professor Roberts with the assistance of Mr. Bloomer.

Especially interesting historically are the eight pages in the introduction devoted to a "History of Geologic and Topographic Maps in Virginia." This section not only refers chronologically to the most important maps, but gives an admirably condensed account of the growth of knowledge of Virginia geology. Significant maps are the three complete geologic maps of the state: (1) Rogers, completed in 1842 but not published until three decades later; (2) Watson in 1911; (3) Nelson in 1928.

The maps are arranged chronologically and grouped into 4 periods. The earliest cited map is dated 1782. The first period is arbitrarily carried to 1840. It is a period in which the maps were primarily geographic and very little concerned with geology. It is carried up to the beginning of Rogers' survey established in 1835 as the first Geological Survey of Virginia. The second period runs from 1840 to 1890 and is nearly coincident with the years of Rogers activity in Virginia. Much headway was made in geologic maps in Virginia during this period, but the mapping was handicapped by a lack of accurate base maps.

The third period extends from 1890 to 1908 when the Geological Survey of Virginia was reestablished under T. L. Watson. The first U. S. Geological Survey topographic quadrangle in Virginia appeared in 1890 and other quadrangles and geologic folios followed, providing for the first time adequate base maps for accurate geologic mapping. The fourth period embraces the span of the present Geological Survey of Virginia.

All of the maps listed are well annotated, giving the date, scale, size, description, and in the case of the older and rarer maps citing libraries in which they are found. The catalogue includes a total of 970 maps.

Useful addenda are an alphabetical list of geologic formational names used in the stratigraphy of Virginia with the name of the author and the date of introduction and a list of the names used by Rogers.

The usefulness of the catalogue is enhanced by a comprehensive index of authors and of subjects. The catalogue will save much time for all

geologists who may have occasion to use the geologic literature of Virginia or to do geologic work in Virginia.

JOSEPH T. SINGEWALD, JR.

THE JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MARYLAND.

Structural and Field Geology. 5th Edit. By JAS. GEIKIE. Rev. by R. CAMPBELL AND R. M. CRAIG. Pp. xxiv + 395. Pl. 69; Figs. 147. Oliver and Boyd, Edinburgh, Scotland. 1940. Price, 25 s.

In the twenty years since the 4th edition of this well-known book was published there has been great progress made along geological lines, but there is little change in the features of the new edition as compared with its predecessor. There have been a few changes in the figures illustrating the text and about a third of the older plates have been replaced by better ones. The general method of treatment of the text in the older edition has been in large measure retained in the new one. A small amount of matter "which was thought unlikely to be of value to students has been discarded," and "many of the new ideas and terms in tectonic and economic geology, which have gained acceptance in recent years" have been introduced. Moreover the concluding chapter, of the earlier editions, on geological structures and surface features, has been omitted.

On the other hand the 90 pages devoted to rock-forming minerals and rocks and the 15 pages devoted to alteration and metamorphism have been rewritten and in general brought up to date, although one misses entirely all reference to the clay minerals other than kaolinite. The chapters on the classification and description of igneous and metamorphic rocks are especially satisfactory in their present form. Both outline modern views on both classes of rocks in sufficient detail for undergraduate geology students. The chapter on the igneous rocks is well illustrated with many plates of photomicrographs of the different types. The chapter on metamorphism is short, but is clearly written and it contains a concise summary of present state of knowledge of the subject.

On the whole the 5th edition of this popular volume is not very different from the 4th edition. The revision has not materially changed either the manner of treatment or the content of the older edition.

W. S. BAYLEY.

Geology of North America, Vol. I. Edit. by RUDOLF RUEDEMANN AND ROBERT BALK. Pp. 643; Pls. 14; Figs. 53. Gebrüder Borntraeger, Berlin, 1940. Price, 13.60 marks.

This is one part of a series of the Geologie der Erde edited by Dr. Krenkel, and contains the "Introductory Chapters" and the "Geology of the Stable Areas" with 16 contributions from among North American

geologists. The second volume, to appear later, will deal with Appalachia and the Cordillera and the third will treat of Mexico and Central America. In this volume Physiography is treated by J. Harlen Bretz; General Geology of North America, General Paleography, and Past Climates by R. Ruedemann; Geosynclines, Borderlands and Geanticlines by C. Schuchert. Then follow separate areas as follows: Greenland by C. Terchert; Arctic Archipelago by E. M. Kindle; Canadian Shield by M. E. Wilson; Appalachian Plateau and Mississippi Valley by C. Butts; S. Central Lowlands by R. Ruedemann; Atlantic and Gulf Coastal by L. W. Stephenson, C. W. Cooke and Julia Gardner; Canadian Extension of the Interior Basin by geologists of the Canadian Survey. The treatment is authoritative and comprehensive.

The Physiographic Provinces of North America. By W. W. Atwood. Pp. 536; Figs. 281; Infold map. Ginn and Co., Boston, 1940. Price, $4.80.

This is a study of the evolution of land forms by treatment of the various physiographic provinces of the continent. It is meant also as a groundwork for the study of geography. Each of the ten provinces are treated in as many chapters, wherein the physical features, geology, structure, glaciation, evolution of land forms, scenic features and human features are treated. More geography is included than is customary in geomorphologic treatments. Each chapter contains selected references and lists of topographic maps of the areas. The illustrations are numerous and good. The writing is facile and the content instructive.

BOOKS RECEIVED.

DAVID GALLAGHER.

Metal Provinces in the Dutch East Indies. (In Dutch.) J. Westerveld. Pp. 30. North Holland University. Amsterdam, 1939. *A lecture.*

Report of the Geological Survey Branch for 1938–39. 33rd Annual Report, New Zealand Geol. Surv. Pp. 15. Wellington, 1939.

Geology of the Naseby Subdivision, Central Otago. J. H. Williamson. Pp. 150; pls. 33; figs. 28; tables 32; 2 text maps in color, 8 geologic maps in color, scale 1:63,360, covering about 960 square miles of contiguous districts lying about 30 miles north of Dunedin. New Zealand Geol. Surv., Bull. 39. Wellington, 1939. Price, 21s. *Detailed geologic description of a region composed mainly of metamorphic rocks and Mesozoic and Tertiary sediments; low grade lignite deposits and small, worked-out, alluvial and quartz lode gold deposits.*

Foraminifera, Diatoms, and Mollusks from Test Wells near Elizabeth City, North Carolina. L. G. Henbest, K. E. Lohman, and W. C. Mansfield. Pp. 12; figs. 2. U. S. Geol. Surv., Prof. Paper 189–G. Washington, 1939. Price, 10 cts.

Fossil Plants from the Colgate Member of the Fox Hill Sandstone and Adjacent Strata. R. W. BROWN. Pp. 37; pls. 17; figs. 1. U. S. Geol. Surv., Prof. Paper 189–I. Washington, 1939. Price, 15 cts.

The Mineral Industry of the British Empire and Foreign Countries; Statistical Summary (Production, Imports and Exports) 1936–1938. Imperial Institute. Pp. 453. London, 1939. Price 7s. 6d.

The Mineral Resources of the Philippines for the Years 1934–1938. Part I—Gold Mines. W. F. BOERICKE AND N. N. LIM. Pp. 135; figs. 10. Philippine Dept. of Agriculture and Commerce, Tech. Bull. 13. Manila, 1939. *Useful summary of mines by districts, giving organization, history, geology, production, mining and milling methods, tonnage and grade, and so forth, for each mine.*

Placer Operations of North Mindanao Mining Co., Surigao, Mindanao. W. F. BOERICKE AND N. N. LIM. Pp. 18; figs. 4. Philippine Dept. of Agric. and Comm., Bureau of Mines, Info. Circ. No. 1. Manila, 1939. *Operating details, geology.*

Preliminary Report on Manganese Ore Benefication at Grawfus Mining Co,. Dirique, Ilocos Norte. W. F. BOERICKE AND N. N. LIM. Pp. 10; pls. 3. Philippine Dept. of Agric. and Comm., Bur. of Mines, Info. Circ. No. 2. Manila, 1939.

Mining and Milling Methods and Costs at the Lepanto Consolidated Mining Co., Mankayan, Mountain Province, Philippines. W. F. BOERICKE, N. N. LIM, AND F. E. JOHNSON. Pp. 20; figs. 4. Philippine Dept. of Agric. and Comm., Bur. of Mines, Info. Circ. No. 3. Manila, 1939.

Mining Industry in the Philippines. Pp. 21; photos 4; map 5″ × 7″. Philippine Dept. of Agric. and Comm. Manila, 1939. *Publicity pamphlet with sketch map of mineral localities.*

Fourth Annual Report of the Director of Mines. Q. A. ABADILLA. Pp. 20. Philippine Bur. of Mines. Manila, 1939. *Mimeographed, administrative, summary of years work in geology and mining.*

The Kimberlite Province and Associated Diamond Deposits of Tanganyika Territory. G. J. WILLIAMS. Pp. 34; pls. 3; maps 2. Tanganyika Geol. Surv., Bull. 12. Dar es Salaam, 1939. Price Shs 3/.

Geology of the Draper Mountain Area, Virginia. B. N. COOPER. Pp. 110; pls. 23; figs. 4. Virginia Geol. Surv., Bull. 55. University, 1939. *Sixteen thousand feet of Paleozoic sediments with several folded, low-angle, thrust planes, and later faulting; unimportant iron, coal, and building stones.*

Geology of the Keezhik-Miminiska Lakes Area. V. K. Prest. Pp. 21; pls. 7; figs. 1; map in color 31″ × 22″, scale 1:63360. Ontario Dept. Mines, 48th Annual Rpt., Pt. 6, 1939. Toronto, 1939. *Typical Canadian Shield geology, quartz veins, but none known of workable grade.*

Geology of the Ashigami Lake Area. H. W. FAIRBAIRN; and Notes on Several Properties in the District of Sudbury. T. C. PHEMISTER. Pp. 31; pls. 13; figs. 1; map in color 22″ × 18″, scale 1:31680. Ontario Dept. Mines, 48th Annual Rpt, Pt. 10, 1939. Toronto, 1939.

Gmelins Handbuch der anorganischen Chemie—Platin. E. PIETSCH ET AL. System Nr. 68. Teil A, Lieferung 3; **Darstellung der Platinmetalle;** Pp. 125. Auslandspreis RM 14.25. Teil C, Lieferung 1; **Verbindungen bis Platin und Wismut;** Pp. 144; figs. 13. RM 16.50. Teil C, Lieferung 2; **Verbindungen bis Platin und Caesium;** Pp. 127; figs. 3. RM 14.25. Verlag Chemie, G.m.b.H., Berlin, 1939 and 1940.

Publications on the Geology, Mineral Resources, and Mineral Industries of Illinois. Pp. 116. Illinois Geol. Surv. Urbana, 1940. *A superb bibliography and index.*

Relatório Anual do Diretor—1937. Pp. 112. Brazil Serv. Geol. e Min. Rio de Janeiro.

Geologia e Hidrologia do Noroeste da Baía. J. L. DE MELLO, JR. Pp. 103; figs. 35; two geol. maps in color, 16″ × 17″ scale 1 : 750,000, and 12″ × 11″ scale 1 : 1,000,000. Brazil Serv. Geol. e Min., Bol. 90. Rio de Janeiro, 1938.

Geologia do Baixo Amazonas. P. DE MOURA. Pp. 91; geol. map in color, 14″ × 14″ scale 1 : 2,750,000. Brazil Serv. Geol. e Min., Bol. 91. Rio de Janeiro, 1938.

Escarpas do Rio de Janeiro. A. R. LAMEGO. Pp. 72; figs. 55; geol. map of the city of Rio de Janeiro, 33″ × 21″ scale 1 : 30,000. Brazil Serv. Geol. e Min., Bol. 93. Rio de Janeiro, 1938. *Detailed stratigraphy, structural geology, and geomorphology of one of the grandest scenic spots of the World; many fine structural diagrams and sections.*

Geologia do Sul de Goiaz. A. I. ERICHSEN AND J. MIRANDA. Pp. 60; figs. 30; 3 sketch maps. Brazil Serv. Geol. e Min., Bol. 94. Rio de Janeiro, 1939.

Geologia da Faixa Subandina da Bolívia. G. DE PAIVA, J. M. REYES, AND G. MARIACA. Pp. 83; numerous unnumbered diagrams and figs.; geol. map in color 10″ × 11″ scale about 6,200,000. Brazil Div. de Geol. e Min., Bol. 101. Rio de Janeiro, 1939. *A cooperative study by the Director of the Brazilian Survey and two Bolivian Government geologists, aimed to produce the most comprehensive, up-to-date, and authoritative account of the geology of these important oil fields.*

Platinum Deposits of the Goodnews Bay District, Alaska. J. B. MERTIE, JR. Pp. 28; pls. 1; figs. 3. U. S. Geol. Surv., Bull. 910-B. Washington, 1939. Price 15 cents. *Placer platinum derived from dunite.*

Geology of the Searchlight District, Clark County, Nevada. E. CALLAGHAN. Pp. 53; pls. 12; figs. 9. U. S. Geol. Surv., Bull. 906-D. Washington, 1939. Price 40 cents. *Oxidized gold-silver-copper-lead deposits; general geology and descriptions of the mines.*

The Mizpah Coal Field, Custer County, Montana. F. S. PARKER AND D. A. ANDREWS. Pp. 48; pls. 25; figs. 5. U. S. Geol. Surv., Bull. 906-C. Washington, 1939. Price $1.50. *1,366,900,000 tons of lignite.*

SCIENTIFIC NOTES AND NEWS

R. T. CHAMBERLIN of the University of Chicago, delivered the biennial Grant Memorial Lectures at Northwestern University this year with several lectures on the "Structure of the Northern Rockies." The series also included one popular lecture on "Earthquakes."

WILLIAM PARRISH was awarded the Walker Prize of the Boston Society of Natural History for a paper based on a portion of his S. F. Emmons Fellowship Report on "The Reflectance of Opaque Minerals."

G. C. BATEMAN has been elected president of the Canadian Mining Institute.

D. G. THOMPSON, of the U. S. Geological Survey, spoke recently on "Ground Water Problems in Ohio," before the department of geology and geography of Northwestern University.

A. W. G. WILSON has been appointed chief technical consultant of the Mines and Geology branch of the Department of Mines and Resources of Canada.

H. E. MCKINSTRY has gone to Madison, Wisconsin, where he is to be acting professor of geology at the University.

G. N. BJORGE, general manager of the Homestake Mining Co., was elected a director of the company at the annual meeting in San Francisco.

D. L. EVANS, who has been resident geologist for Climax Molybdenum Co., has gone to Reno, Nevada, where he has accepted a position with the Freeport Sulphur Co.

H. C. HORWOOD, geologist of the Ontario Department of Mines, is preparing maps and reports on the Red Lake district of Northwestern, Ontario.

C. N. SCHUETTE, mining engineer of San Francisco, has been made manager of the New Almaden Corp., organized to reopen and operate the quicksilver property in Santa Clara County, California.

A. L. RANSOME and O. P. JENKINS are preparing a series of economic mineral distribution maps of California.

Sir L. L. FERMOR, who has recently returned from India, is now located at 24, Durdham Park, Bristol, 6, England.

N. H. FISHER, government geologist of New Guinea, has been appointed assistant government geologist of South Australia.

E. K. NIXON is on leave of absence from the Oregon Department of Geology and Mineral Industries to investigate iron-ore possibilities in Peru.

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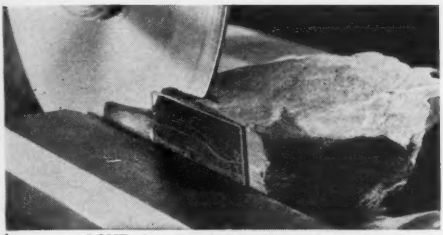

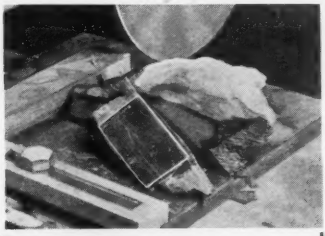

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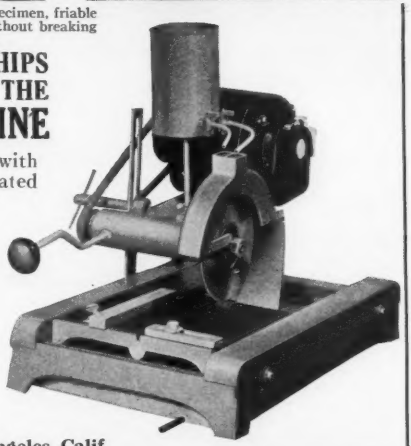

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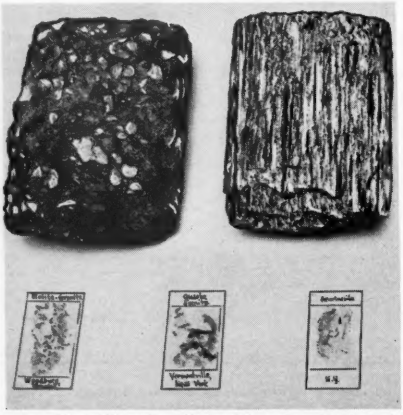

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